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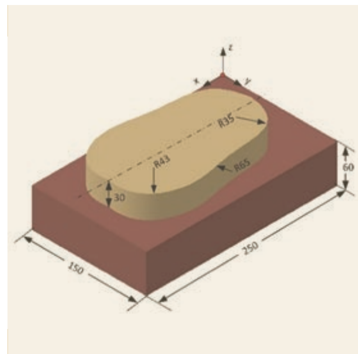

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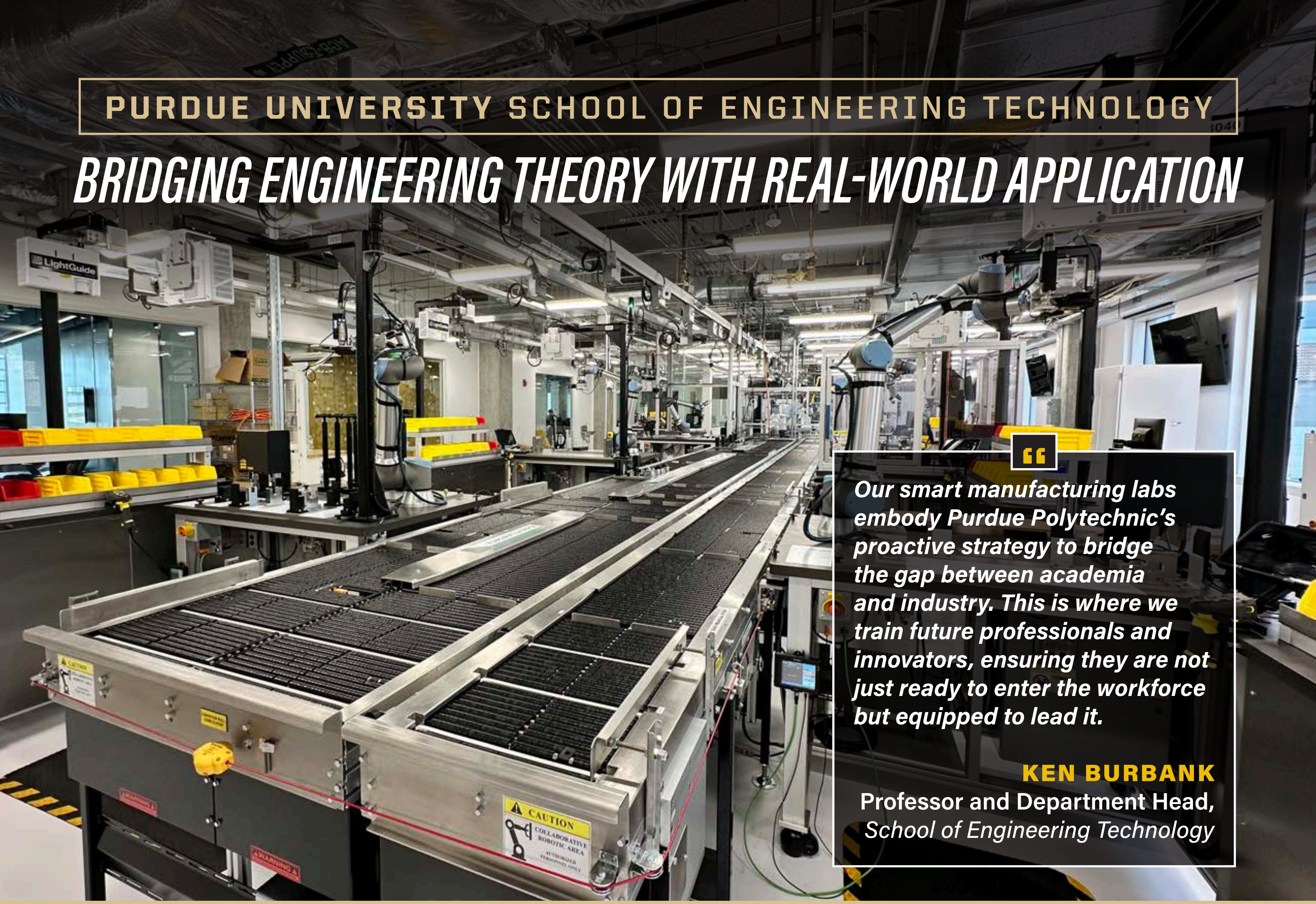

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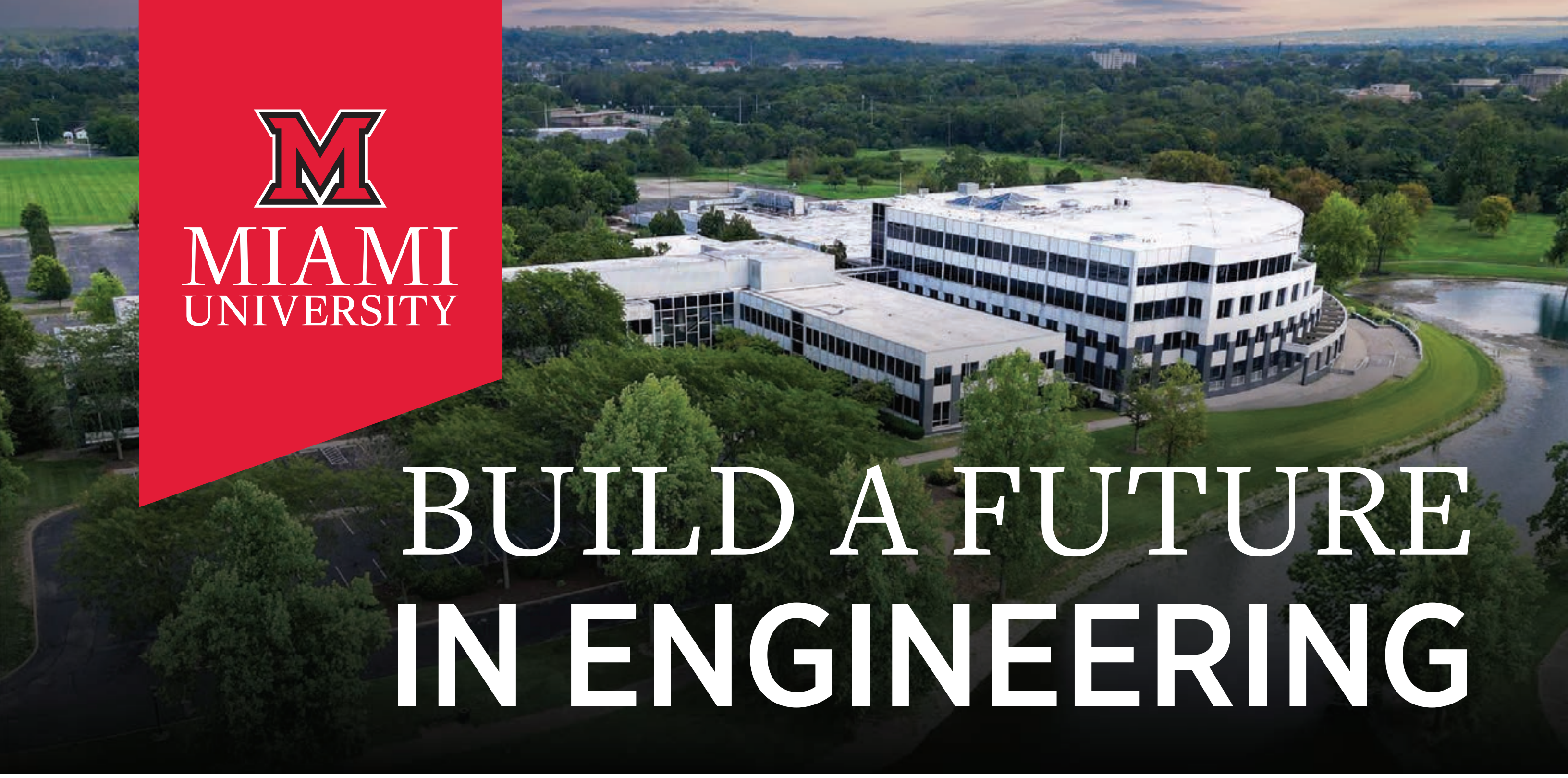

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From the EDITOR

Dear Colleagues:

It was a true pleasure to connect with so many colleagues and community members from the engineering technology field at ASEE 2025. The conference highlighted an impressive number of papers showcasing the latest trends and innovations, and I am delighted to share that our journal session was very well received. I extend my sincere thanks to all who attended and participated.

This summer, the latest journal impact factors were released, and I am proud to report that the *Journal of Engineering Technology®* achieved an impact factor of 1.6, remaining in the second quartile. Our journal is also listed in the Master Journal List of Web of Science and included in the Science Citation Index Expanded (SCIE). These ratings firmly position *JET* as one of the leading journals in engineering, and we look forward to publishing and disseminating your important work. Please feel free to reach out if you have any questions.

After an extensive search, the editorial board is pleased to announce the appointment of two outstanding colleagues:

- Dr. Farid El Breidi of Purdue University is the new Production Editor
- Dr. John Irwin of Michigan Tech University is the new Advertising Editor

Please join me in congratulating them on their new roles.

This issue of the *JET* features four diverse and timely contributions. The first paper explores the unique challenges and opportunities student veterans face when pursuing engineering or engineering technology degrees, emphasizing strategies for successful integration and retention. The second paper introduces a hands-on fluid power lab kit and modules that enhance student engagement and bridge theory with practical applications. The third paper examines alumni perspectives on a Technology Management program, highlighting its evolution, career impacts, and lessons for supporting students in engineering technology pathways. The fourth paper presents the revised Four Pillars of Manufacturing Knowledge, integrating advanced manufacturing concepts such as Industry 4.0, additive manufacturing, and digital manufacturing to better align with the future of the discipline.

As always, the editorial board deeply values your contributions and continued support in advancing engineering technology education and research.

All my best,

Ismail Fidan, PhD
Editor-in-Chief
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Choosing Between Undergraduate Engineering and Engineering Technology Academic Programs for Student Veterans

Bradley J. Sottile and Robert J. Rabb

DOI: 10.18260/jet.42.2.1

Abstract

Student veterans have a unique opportunity to pursue higher education post-discharge via successive offerings of the G.I. Bill program. Academic program preferences for veteran students have important implications across an organizational field where attention has sharpened on student matriculation, persistence, and retention. Some student veterans may pursue an engineering degree while others may earn a two- or four-year engineering technology degree. Student veterans should be aware of the differences in these degrees and the career opportunities in each. Some may put their technical military experience to use in higher education, while others may pursue a radically different educational path. There are numerous activities and processes employed both before student veterans arrive and during their time on campus to ensure they are part of the campus community and to ensure they graduate with an engineering or engineering technology degree within their timeline. These efforts can create a culture of open communication with student veterans and increase engagement of these students with faculty, engineering professionals, and peers to matriculate them into the campus engineering community.

1. Introduction

Through the lens of organizational theory, this work examines undergraduate engineering and engineering technology opportunities at The Pennsylvania State University (Penn State), a large, public, research-intensive, state university, in the northeast United States, with respect to program selection and retention, ultimately using mixed methods surveys (future work). This paper will inform a more detailed study to gain insight for advising and policymaker efforts to better serve this unique student population. The demand for engineering and engineering technology degrees is expected to increase, and large numbers of student veterans will continue to enroll in higher education institutions, necessitating the need for increased attention on this student subgroup. The U.S. has a national interest in increasing and maintaining the number of Science, Technology, Engineering, and Math (STEM) professionals in the workforce (Wilkinson 2023), and this group will be part of the STEM professions.

Penn State is a land-grant, state institution with multiple campuses geographically dispersed throughout the state. Some campuses offer traditional four-year engineering degrees, while many of the smaller campuses offer a myriad of engineering technology degrees. The availability of engineering offerings is tremendous. However, approximately 25% of the student veteran population attends the main or flagship campus to earn a four-year engineering degree while 75% of the student veteran population attends one of the much smaller campuses, often earning an engineering technology degree.

This paper explores considerations for student veterans in choosing a two-year engineering program versus a traditional four-year engineering program. Two-year technical degrees are typically offered at junior or technical colleges, while the four-year engineering programs are offered at many traditional universities and colleges. This paper will focus on the differences between the two types of institutions and the veterans' backgrounds, priorities, and means to higher education. The student population in this paper refers to student veterans and reservists (and not to their family members).

Higher education and the national drive to support military-connected students is often limited by an insufficient understanding of this diverse student population. Nearly all the veteran education benefits have time limits, financial limits, and proof of satisfactory academic progress for accountability and oversight of limited resources. Many state university campuses may have a Veterans Affairs and Services Office, but they offer many services in addition to information and guidance on education benefits. Some employees may be tasked to organize military appreciation events, provide general campus information, and sometimes even childcare, etc. Additionally, the concentration of this knowledge and the services in one building may be inconvenient to some students, especially on large campuses. Some large campuses offer military ally training (e.g., Green Zone Training), short courses aimed at instructors to promote awareness of military and veteran students' challenges and differences from traditional students. However, specific knowledge of the rules and policies of education benefits is often centralized among the staff at the campus advising or Veteran Affairs and Services Office, or to a few service-connected individuals in the academic units. Professional advising staff often focus on traditional students and the set curricula. Moreover, professional advising staff experience frequent turnover.

2. Background

Post-World War II, the higher education landscape evolved in several ways. The growth and importance of higher education were already felt before the war, and there was resistance from elite universities and presidents who believed higher education was a rite of passage for the elite who were gifted and had merit. Higher education became an important priority to improve the quality of life and expand opportunities for the middle class, hence the growth of state colleges and universities, along with community or junior colleges. When students were less academically prepared for a traditional baccalaureate degree, students used junior colleges as preparation venues (Brint 1989). Elite colleges were sometimes supportive of the junior colleges to meet demand for higher education while simultaneously limiting growth at their elite institutions (B. Clark 1960).

World War II veterans were like their civilian peers on campuses in their career goals. Student veterans wanted new courses in business, economics, and engineering, and sought changes to humanities courses so they could be more relevant to real life in an industrialized, post-World War II America (D. Clark 1998). Due to the demand of over 2 million veterans seeking bachelor's degrees (Serow 2004), physical expansion was necessary, resulting in large lecture halls and temporary living quarters on or near campuses (D. Clark 1998). This expansion changed the perception of the country's population, who now saw that college was not only for the elite, but it was also available and for the average citizen (D. Clark 1998; Serow 2004; Thelin 2004).

With the return of 2 million service personnel back to mainstream America at the close of World War II, the United States government established the original GI Bill, the Servicemen's Readjustment Act of 1944. The Act initiated a wide-ranging series of benefits and programs to help ease veterans back into American society without burdening the American workplace. The most prominent benefit of the GI Bill was the educational component, but the Servicemen's Readjustment Act included unemployment benefits, business loans, home loans, and training opportunities, allowing the veterans to go to college. After World War II, student veterans used the GI Bill to pursue higher education goals and contributed to the diversity of university and college populations. Since 1944, there have been six iterations of GI Bill educational programs. The most recent one is known as the Post-9/11 GI Bill, which was implemented in the fall of 2009 (Vacchi 2014). Since 2009, the Post-9/11 GI Bill has been a significant investment to support higher education for more than 1.4 million service members, veterans, and their families (Molina and Morse 2015).

3. Current Education Funding

This section highlights two of the most common ways student veterans receive federal funding to pursue their degrees. There is a myriad of programs to assist with disabilities and other special situations, but most student veterans use the following sources. For clarity, tuition assistance is what veterans may use while still in the military, whereas the GI Bill is the tool they use once they have exited the military.

3.1. Tuition Assistance

The Tuition Assistance (TA) program provides funding for voluntary civilian education programs in support of a service member's professional and personal self-development goals. Such work is done during off-duty times. Courses and degree programs may be academic or technical and can be taken from a variety of sources and modalities, including two- or four-year institutions, on-site, off-site, or distance learning. The U.S. Department of Education must recognize the higher education institution. In the TA program, the service branch pays tuition directly to the school, not the service member. TA may be used for:

- Vocational/technical programs
- Undergraduate programs
- Graduate programs
- Independent study
- Distance-learning programs

All service branches and the U.S. Coast Guard offer the TA program to support the users' personal and professional goals. The program is open to officers, warrant officers, and enlisted active-duty service personnel. In addition, members of the National Guard and Reserve Components may be eligible for

TA based on their service eligibility (have enough remaining time on their service contract to complete the course). Some TA recipients may be required to fulfill a short service obligation that can run parallel to their current service obligation. TA only covers tuition and not logistics such as books and course materials, special training fees, retaking the course, or continuing education units (CEUs) (Military One Source 2013).

3.2. Post-9/11 GI Bill

The GI Bill allows current and former service members to pay for college, trade school, technical school, licensing, certification programs, on-the-job training, online schooling, and more. The Post-9/11 GI Bill provides benefits for those who served on active duty or in the Selected Reserve for 90 or more days after 10 September 2001. The GI Bill allows four academic years (36 months) of educational tuition benefits for an approved program up to the cost of the most expensive in-state undergraduate public tuition in the state where the veteran enrolls. Additional tuition at more expensive private schools under the "Yellow Ribbon" program allows participating institutions to share the cost (usually, one-to-one) with the federal government up to 100% of the expense. Other benefits include:

- A monthly living allowance based on housing costs of the location of the learning institution. Student veterans attending schools online or through correspondence will receive a partial benefit if their entire enrollment is in distance or online learning. The student veteran will receive a living allowance if at least one course is classified as "in-residence."
- International education programs outside the United States are eligible.
- An annual stipend up to $1,000 to cover other education costs (e.g., books, supplies, and fees).
- Up to $2,000 towards one-time licensing or certification testing (U.S. Department of Veterans Affairs 2024a).

4. Where Veterans Choose to Go to College

Not every higher education institution has the same distribution of student veterans. One study (Radford 2009) showed that student veterans resemble nontraditional students when choosing college type and degree choices. The study found approximately 12% of student veterans attend private for-profit institutions and 64% attend public institutions - results which are quite different from traditional student enrollment patterns. Student veterans also attend public community colleges at a rate of 43%, and they attend four-year institutions at a rate of 57%. However, 89% of student veterans pursue bachelor's or associate degrees, and slightly more student veterans pursue bachelor's degrees than associate degrees. This implies that a fair percentage of student veterans at community colleges continue to pursue further study at four-year colleges.

5. Why Two-Year vs. Four-Year Institutions

Education centers on military installations offer a variety of transition services to help potential student veterans decide where to attend college and what type of degree or campus. A two-year institution, such as a community college or a junior college, can offer some advantages to veterans, like cost-effectiveness, smaller class sizes, and more flexible scheduling. However, a four-year institution may provide a more comprehensive academic experience and a wider range of extracurricular activities (U.S. Department of Veterans Affairs 2016). Some key points and differences are elucidated in Table 1.

There are potential advantages for student veterans at two-year colleges. The lower cost of attendance can help maximize the GI Bill benefits, and the more flexible scheduling can accommodate work or family obligations. Additionally, many community colleges have dedicated veteran support programs (CalVet 2022).

Four-year universities may allow access to advanced research projects, equipment, and faculty expertise (U.S. Department of Veterans Affairs 2016; U.S. Department of Veterans Affairs 2024b; University of Bridgeport 2023), and campus life engagement is different as most universities have a multitude of diverse activities (Mount Wachusett 2023). Student veterans should always research individual institutions and their veteran support services before deciding (U.S. Department of Veterans Affairs 2016; Jordan 2019; CalVet 2022).

6. What Student Veterans Choose to Study

Student veterans pursuing a technical degree have many options when choosing between engineering technology programs and more traditional engineering programs. As noted in the literature (Florida Polytechnic University 2024), an engineering degree focuses on theory and advanced concepts, while an engineering technology degree focuses on practical applications and hands-on work. Kuehn, in studies of engineering technology workforce trends, specified that students earning 2-year engineering technology degrees are termed "technicians," and those earning 4-year engineering technology degrees "technologists" (2015). The 2017 National Academy of Engineer-

Table 1. Two-year and four-year institution comparison.

	Two-Year	Four-Year
Cost (U.S. Department of Veterans Affairs 2024b; Going Merry 2024; University of Bridgeport 2023)	Significantly lower tuition fees compared to a four-year university, making it a cost-effective option for veterans utilizing GI Bill benefits	Higher tuition costs, though some may offer veteran-specific scholarships or reduced tuition rates
Academic Focus (U.S. Department of Veterans Affairs 2016; U.S. Department of Veterans Affairs 2024b; University of Bridgeport 2023)	Offers foundational courses and associate degrees, providing a good base for subsequently transferring to a four-year program	More specialized majors and more advanced coursework, often with greater research opportunities
Class Size (Going Merry 2024; University of Bridgeport 2023; Jordan 2019)	Smaller class sizes, potentially allowing for more personalized attention from instructors	Larger class sizes, especially in introductory courses, may be less intimate
Flexibility (Going Merry 2024; Jordan 2019; Travis County 2025)	Often offers flexible scheduling with evening and weekend classes, accommodating veterans with work or family commitments	May have more rigid class schedules, though some flexibility may exist depending on the institution
Campus Life (Going Merry 2024; University of Bridgeport 2023; Mount Wachusett 2023)	Typically, a less vibrant campus life with fewer extracurricular activities and student organizations	More robust campus culture, with a wider array of clubs, sports, and social events
Transferability (U.S. Department of Veterans Affairs 2016; U.S. Department of Veterans Affairs 2024b; University of Bridgeport 2023)	Student veterans must carefully research transfer agreements between community and junior colleges and four-year institutions to ensure their credits will transfer smoothly	

ing report (Frase, Latanision, and Pearson 2016) on engineering technology education adopted a similar nomenclature, though concurrently shared the observation that "many of those with 4-year [engineering technology] degrees do not identify themselves as technologists" and instead "they may call themselves engineers or managers."

Terminology aside, a recent study (Wilson 2024) investigated the top reasons students select an engineering technology major. The study reinforces the idea that students in general select engineering technology programs due to hands-on learning, multiple lab experiences, and math requirements. Students have expressed concerns when choosing STEM vs. non-STEM studies, specifically, some have anxiety in knowing math (theoretical) and doing math (applied). Mathematicians, engineers, and natural scientists depend more heavily on the theoretical application of math, while social scientists and technologists depend more heavily on its practical application. Technologists also need more mathematical literacy than non-STEM professionals (Wilkinson 2023). Table 2 offers a side-by-side examination of the differences between engineering and engineering technology.

7. Future Work

This preliminary study will shape future work and will involve student veterans and campus staff, and administrators. Although this university is a complex system of a main campus with nearly two dozen smaller campuses, the investigators hope to generalize the factors that student veterans consider pursuing a two-year engineering technical degree versus a traditional four-year engineering degree. Because of the unique characteristics of the subject institution's campus system and the state's rurality, the investigators welcome partnering with other institutions to deepen and broaden their understanding of student veterans' higher education goals.

8. Conclusion

Given the imbalance of student veterans attending this institution's distributed campuses versus the flagship main campus, the authors would like to better

Table 2. Engineering vs. Engineering Technology.

	Engineering	Engineering Technology
Theoretical Versus Practical (Excelsior 2024; Polk 2025)	Involves an in-depth study of advanced mathematics and scientific theories to create new ideas and solutions.	Focuses on applying existing methods to problems and on using technology, applied science, and mathematics to solve problems
Hands-On Versus Theoretical (New Hampshire 2022)	Tends to be more theoretical and analytical	Tends to be more hands-on and applications-oriented
Specialization (Polk 2025; Grand Canyon 2016)	One can focus on a specific area of engineering, such as aerospace engineering or mechanical engineering	One can focus on a specific area of engineering technology, such as advanced manufacturing or mechanical design and fabrication
Career Paths (Excelsior 2023; New Hampshire 2022; Grand Canyon 2016)	Engineers can work in design, research, and other theoretical roles	Engineering technologists can work as liaisons between engineering and manufacturing teams, or as design and testing partners to engineers

understand student veterans' decision-making and the factors involved.

Student veterans are non-traditional students, and reviews of the extant research literature suggest there is more exploration needed to better understand their engineering degree and school choices, including introspection of their positionality as non-traditional students. That said, student veterans have been on college campuses for decades and are not a 'new generation.' The gaps in understanding this population are great compared to the literature on traditional college student populations. Prior research on student veterans points others in the direction to continue investigations and towards a better understanding of student veterans.

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Bradley J. Sottile

Brad Sottile is an Associate Teaching Professor in The Pennsylvania State University's College of Engineering, School of Electrical Engineering and Computer Science. He received his D.Eng. from The Pennsylvania State University focusing on engineering education. His research interests include astronautical engineering, computational science, and engineering and higher education.

Robert J. Rabb

Robert Rabb is the Associate Dean of Education and a Teaching Professor in The Pennsylvania State University's College of Engineering. He earned his B.S. from USMA and his M.S. and PhD from the University of Texas at Austin. His research interests are in mechatronics, regenerative energy, and engineering education.

Bridging Theory and Practice: A Novel Educational Lab Kit for Fluid Power Instruction

Mohammed Metwaly, Farid El Breidi and Jose M. Garcia-Bravo

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Abstract

Fluid power is a multidisciplinary field crucial to various engineering applications. Introducing it early in the engineering curriculum helps students understand foundational principles critical for future work in fields such as mechanical, civil, and aerospace engineering. This paper presents a lab kit and five educational modules designed to teach core fluid power principles and support electro-mechanical technologies through hands-on activities. Each module focuses on specific learning objectives, bridging the gap between theory and practice. Students engage in activities like constructing and controlling a pneumatic gripper, calibrating a sensor with a custom-built deadweight tester, and grasping data acquisition skills using Arduino and pressure transducers. The lab kit was tested by junior and senior engineering technology students, providing a novel approach to reinforce fluid power technology concepts. Preliminary feedback suggests this approach increases student engagement, interest in fluid power, and perceived performance and competence. The kit's versatility allows for future exploration of additional fluid power concepts and learning outcomes.

1. Introduction

Fluid power is a foundational field within engineering, supporting essential applications across various sectors, including manufacturing, aerospace, and transportation. For engineering students, hands-on experience in fluid power technology is beneficial for developing a comprehensive understanding of mechanical and control systems. Introducing fluid power through practical lab work early in the curriculum helps bridge the gap between theoretical knowledge and real-world application, reinforcing essential skills and preparing students for industry demands (Chen et al. 2019; Persky and Sauret 2016).

Fluid power education faces significant challenges in providing accessible and comprehensive lab experiences. Many programs prioritize hydraulics over pneumatic systems, limiting students' exposure to the full range of fluid power applications (Assaf and Vacca 2021). High equipment costs, limited laboratory space, and difficulty replicating real-world systems further restrict practical engagement (Fox et al. 2020; Lovrec 2019). While simulations and videos are useful teaching tools, they fail to fully capture the complexities of real-world systems, leaving gaps in students' understanding (Mandal, Azad, and Rasul 2024). These challenges highlight the need for cost-effective and engaging educational solutions that align with industry advancements.

Previous studies underscore the value of lab kits as affordable, flexible tools that enhance hands-on learning, particularly in remote or resource-constrained settings. During the COVID-19 pandemic, lab kits were shown to be effective in distance learning environments, significantly improving student engagement, motivation, and cognitive outcomes (Permana 2022; Wong and Sim 2022). Moreover, Shehadi and Lucietto (Shehadi and Lucietto 2018) demonstrated that incorporating interactive, hands-on exercises in a fluid power course significantly enhanced student interest and performance. These kits allow students to conduct real-time experiments that reinforce theoretical knowledge and support the development of practical problem-solving skills (Azzam et al. 2024; Appiah-Kubi, Johnson, and Trappe 2019), addressing some of the educational gaps identified in fluid power curricula.

Recent advancements in educational tools have demonstrated the effectiveness of modular systems in providing hands-on learning experiences while addressing resource constraints in engineering education (Ma and Pecen 2024). Similarly, the modular lab kit introduced in this paper addresses these challenges by offering a cost-effective and accessible means for students to engage with pneumatic systems. Priced at ~$70, the kit includes five educational modules designed to help students explore core fluid power concepts such as actuation, sensor calibration, and data acquisition. Through activities such as constructing and operating a pneumatic gripper, students gain practical experience that builds both foundational knowledge and applied skills. This lab kit and its modular design enable students and educators to explore additional fluid power concepts.

2. Related Work

Feisel and Rosa (Feisel and Rosa 2005) and Cook (Cook 2020) highlighted the value of lab kits in enhancing problem-solving skills and practical understanding, particularly in manufacturing and engineering technology programs. Permana (Permana 2022) and Wong and Sim (Wong and Sim 2022) demonstrated that lab kits significantly improved student engagement and motivation in remote learning, making them a flexible solution in resource-constrained settings.

Studies by Fox (Fox et al. 2020), Wang (Wang et al. 2021), and Zahraee (Zahraee et al. 2023) emphasized the importance of experiential learning tools for preparing students for industry roles by providing hands-on engagement in fluid power applications. Mandal et al. (Mandal, Azad, and Rasul 2024) showed that combining simulations with physical kits enhances engagement and skill development, as simulations (Azzam, Pate, and Breidi 2023; Azzam et al. 2022) or theory (Mayer 2023) alone lack the tactile interaction needed for operational training.

Earlier efforts, such as portable kits by Zorro et al. (Zorro-Mendoza, Garcia, and Breidi 2021), Pate et al. (Pate et al. 2018) and Mishler et al. (Mishler, Garcia, and Lumkes 2011), introduced students to fundamental fluid flow concepts using simple components. While effective for teaching basics, these kits did not incorporate the electronic controls and data acquisition needed to simulate modern fluid power systems.

Unlike previous kits focused on remote learning or isolated technical concepts, our lab kit offers an adaptable and cost-effective approach to both pneumatic and hydraulic applications, making it a versatile tool for fluid power education.

3. Lab Kit

3.1. Kit Development

The lab kit provides students with hands-on experience in fundamental fluid power concepts, specifically focusing on electro-pneumatic systems to address a gap in standard curricula, which often emphasize hydraulics. Costing $72 (Table 1), the kit is designed to be affordable for institutions with limited budgets, enabling the integration of comprehensive fluid power modules. Additionally, the kit's lightweight components ensure accessibility for students with motor limitations, reducing the need for heavy lifting and making hands-on learning more inclusive.

Table 1. Budget breakdown of lab kit.

Item	Price (in U.S. Dollars $)
Junction Box	21.51
Air Compressor	15.19
LCD Screens	8.99
Arduino Microcontroller	13.59
Breadboard	1.50
Tube	3.99
Syringe	0.75
Pressure Gauge	4.50
Bolts, Hose Barbs, Hose Pushes	1.98
Total:	**72.00**

The kit's components are organized by function (Figure 1): actuation and control (pneumatic gripper and DC air pump motor), sensor calibration and measurement (pressure transducer and deadweight tester), and circuit assembly and data display (Arduino microcontroller, breadboard, and LCD screen).

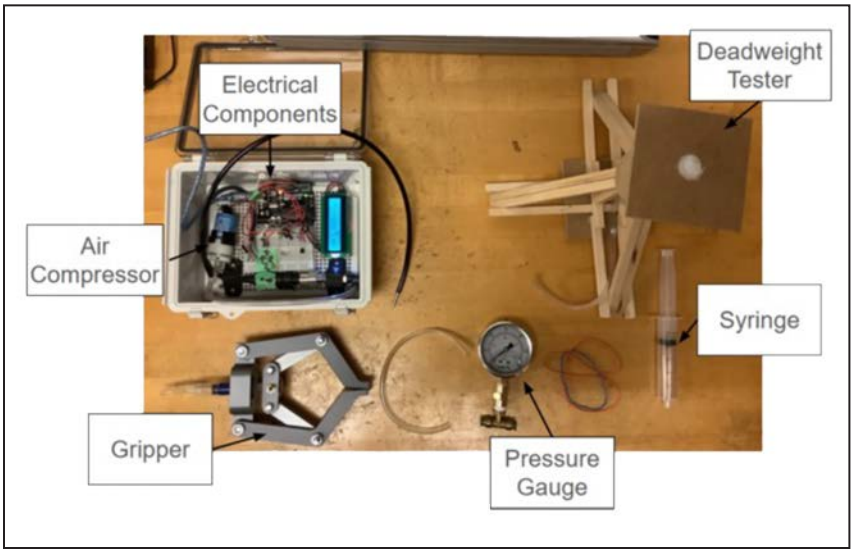

Figure 1. Complete lab kit setup for hands-on fluid power instruction.

Together, these parts allow students to explore fundamental fluid power principles, including system actuation, sensor calibration, and real-time data monitoring, within a cost-effective, modular setup that supports versatile educational use.

Through activities like assembling and controlling a 3-D printed pneumatic gripper and air pump with a microcontroller, students develop skills in electro-pneumatic actuation, simple control techniques, and system responsiveness. The kit reinforces mechanical design and assembly concepts specific to pneumatic systems, introducing students to electro-mechanical integration and circuit design with Arduino. Data collection exercises refine students' measurement skills, particularly in sensor accuracy, to ensure effective pneumatic system monitoring and adjustment. Calibration tasks emphasize sensor reliability, crucial for sustaining system performance in practical applications.

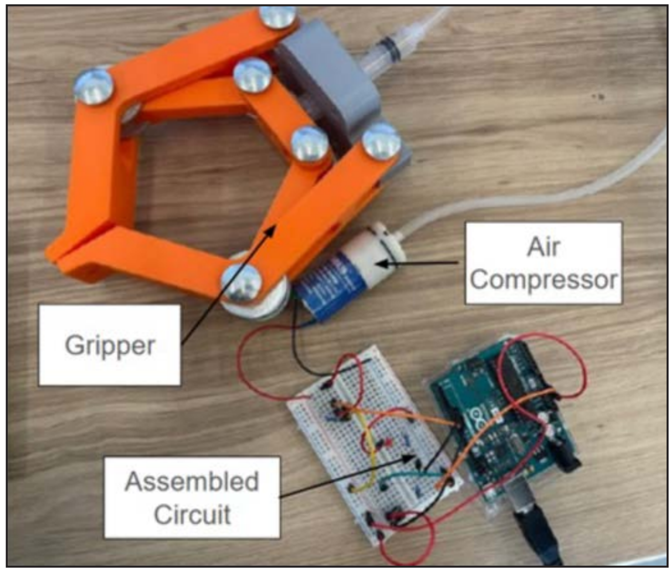

Figure 2. Pneumatic gripper actuation and control setup.

3.2. Kit Lab Modules

The lab kit and associated modules were introduced in classroom settings, where student feedback guided improvements. Initially, three modules focused on pneumatic gripper actuation and control, pressure measurement, and data acquisition using a pressure transducer (Jabbour et al. 2024). Based on the feedback previously obtained, refinements were made to enhance usability, engagement, and educational value, leading to the development of five modules. Designed for multiple uses across different courses and lab sessions, the kit features reusable components such as the pneumatic gripper, sensors, and Arduino microcontroller, ensuring longevity. Only minor consumables, like tubing or syringes, require periodic replacement, making it a cost-effective long-term solution for fluid power education. The kit's modular structure enables scalability, allowing instructors to organize students into groups and efficiently manage larger classes. Additionally, its flexibility supports expanded learning objectives, as educators can incorporate additional lab exercises. Finally, the modular design allows for easy adaptation to hydraulic systems by replacing the air pump with a hydraulic pump, enabling students to explore both fluid power domains using the same experimental setup.

3.2.1 Lab Module 1 - Pneumatic Gripper Actuation and Control

This laboratory module aims to introduce students to the principles of pneumatic actuation and control through the assembly and operation of a pneumatic gripper shown in Figure 2. Students build a light-duty gripper using 3D-printed components and assemble a circuit with an Arduino microcontroller, shown in Figure 3, to control its movement. The

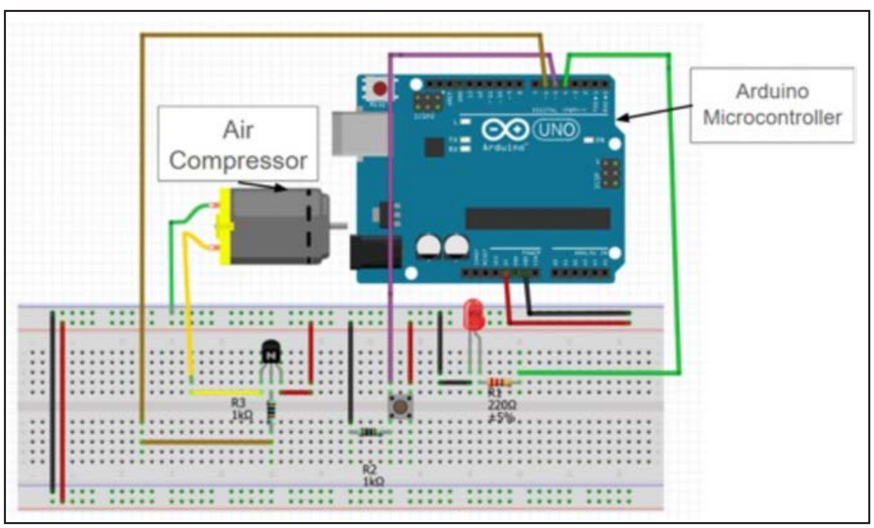

Figure 3. Circuit assembly for pneumatic gripper actuation using an Arduino microcontroller and air compressor.

students write an Arduino script to activate a mini air pump via a push button. Students learn about control techniques in pneumatic systems and observe electro-mechanical integration, gaining hands-on experience related to circuits and programming to control pneumatic mechanisms. Additionally, students are introduced to basic electric component identification and use, such as is the case for the color bands in resistors and the connected paths on a bread board.

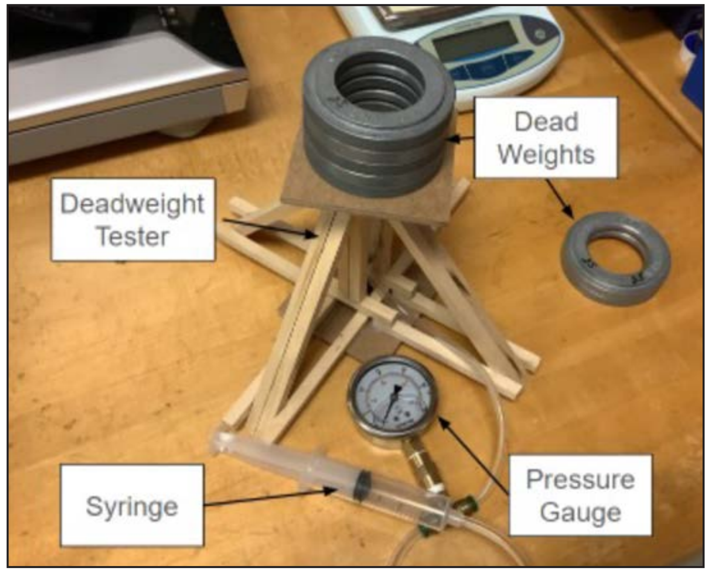

Figure 4. Deadweight tester setup with labeled components, including the syringe, pressure gauge, and dead weights.

3.2.2 Lab Module 2 - Deadweight tester and fluid power relationships

Students design and construct a deadweight tester built with balsa wood to explore the relationships between pressure, force, and area, applying Pascal's principle to pneumatic systems. Short lengths of ¼ inch tubbing are used to reduce the effects of compressibility of the system. The kit shown in Figure 4 depicts the setup, including a syringe, pressure gauge, balsa wood construction, and calibrated weights (other materials with known weights may be used, like bags of rice or other cereals). Students incrementally add weights to measure the pressure load and test different fluids, such as water or air, to observe changes in system performance. This setup enables students to understand force distribution and pressure calibration in fluid power systems through hands-on assembly and testing.

3.2.3 Lab Module 3 - Data acquisition and calibration of a pressure transducer Part I

This module introduces data acquisition and sensor calibration techniques. Students use the deadweight tester (as shown in Figure 5) to generate known pressure values, which they record with a pressure transducer, then process it to establish a calibration equation for converting the transducer's voltage output to corresponding pressure values. Calibration specimens, such as known weight references, are provided to allow students to establish accurate calibration equations for the pressure transducer. The deadweight tester included in the kit serves as a calibration reference, ensuring precise sensor measurements. A manual pressure gauge is included to provide a comparative measure. Students use an Arduino microcontroller to design a circuit that captures real-time voltage readings, reinforcing skills

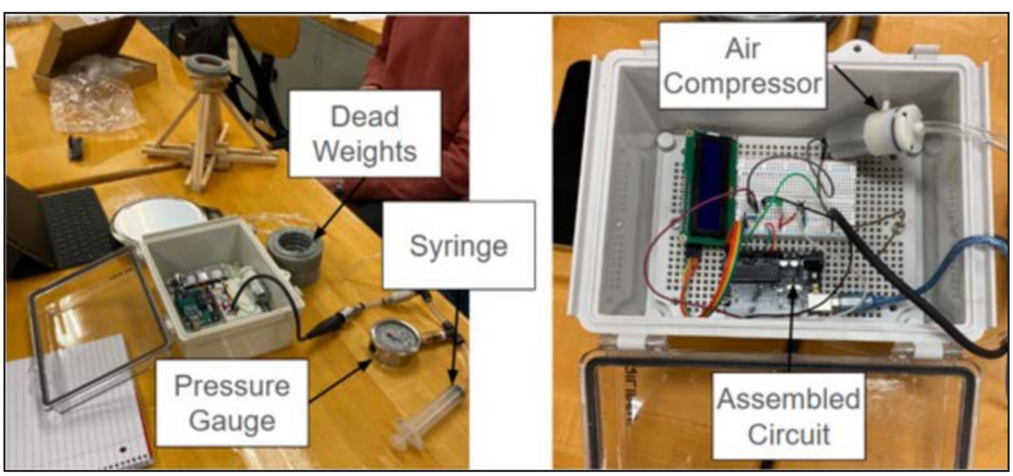

Figure 5. Lab Module 3 setup with deadweights, syringe, pressure gauge, and the assembled circuit containing the pressure transducer and Arduino microcontroller.

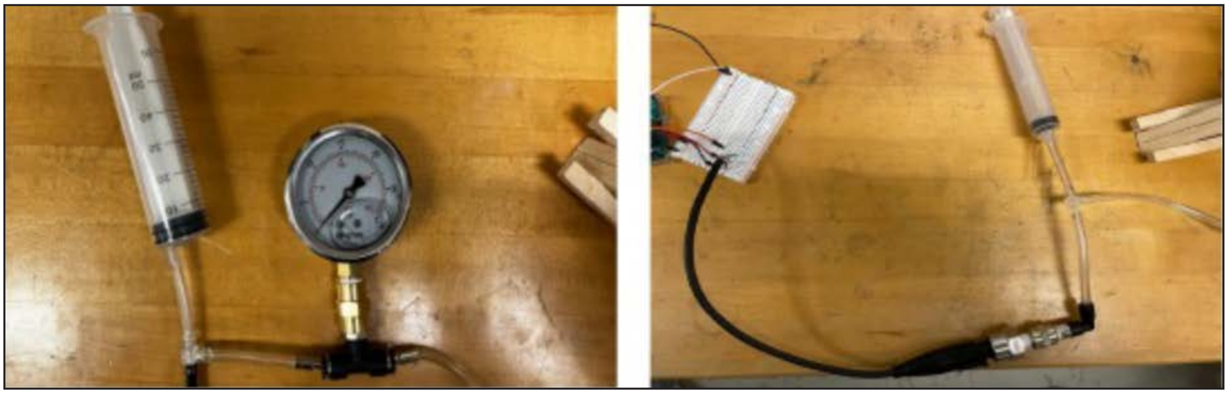

Figure 6. Pressure gauge setup (left) and pressure transducer setup (right) used in the pressure measurement module.

in circuit design, programming, and calibration for accurate measurement in pneumatic applications.

3.2.4 Lab Module 4 - Data acquisition and calibration of a pressure transducer Part II

Building on Module 3, this module focuses on real-time data display and system dynamics. Students set up a circuit with an Arduino and LCD screen to show live pressure data from a transducer integrated with a pneumatic gripper. As shown in Figure 6, students connect the transducer to observe how factors such as hose length and pump power affect system pressure. This exercise enhances students' skills in monitoring and controlling pneumatic systems, deepening their understanding of dynamic instrumentation.

3.2.5 Lab Module 5 - Pressure measurement with a pneumatic gripper using a pressure transducer

This module teaches the students the fundamentals of data collection, calibration, and pressure measurement in pneumatic systems. As shown in Figure 7, students will integrate a pressure transducer with a pneumatic gripper, utilizing an assembled circuit that includes an Arduino microcontroller, air pump, and LCD screen to display pressure data. By configuring this setup, they learn how to integrate a pressure transducer with a pneumatic gripper and hone their circuit design, instrumentation, and programming skills. Students configure the pneumatic system using an Arduino microcontroller, air pump, and pressure transducer as part of the lab process. They then use a controlled gripper actuation to gather pressure data. This configuration reinforces the ideas of sensor precision, dependability, and system monitoring by enabling students to see how pressure varies inside the system and how precise measurements may be recorded and shown.

4. Evaluation

The lab kit was administered to a group of 23 junior and senior engineering technology students enrolled in a fluid power course. Prior to students using the third, fourth, and fifth lab kit modules, a pre-survey using a Likert scale from 1 to 5 was given in order to assess its impact. This survey created a baseline for comparison by evaluating their perceived performance and competency in fluid power, as well as their level of interest in it. Following the completion of these modules, students took part in a post-survey that evaluated their engagement with the lab kit and reassessed their interest and perceived competence. The study sought to ascertain whether students' interest and perceived proficiency in fluid power

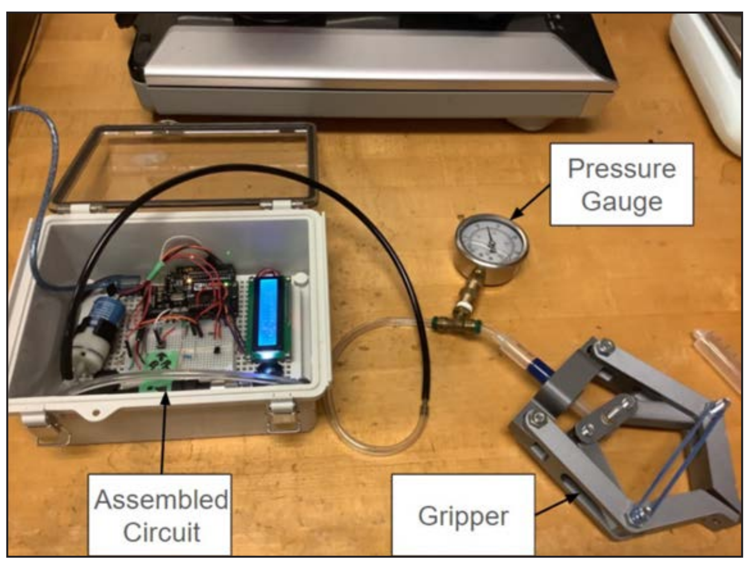

Figure 7. Experimental setup for pressure measurement module, showing the assembled circuit, pressure gauge, and pneumatic gripper.

concepts were improved by the practical experience with the lab kit by comparing their answers to the two surveys. Moreover, the engagement component of the post-survey was designed to assess how engaging students found the lab kit, providing insight into its effectiveness as a learning tool.

Figure 8 presents the average engagement scores across three dimensions: Emotional, Physical, and Cognitive Engagement, highlighting variations in student interaction with the lab kit. Among emotional engagement factors, interest in the lab kit received the highest score, indicating that students found the activities engaging and relevant. However, energy levels were relatively lower, suggesting that while students were interested, they may not have felt highly energized throughout the lab. This could be attributed to the fact that the lab kit was administered as the final lab of the semester, when students may have experienced fatigue from cumulative coursework. In terms of physical engagement, students reported high levels of effort and determination to perform well on assignments, but exertion scored the lowest, indicating that the tasks were not physically demanding. This aligns with the lab kit's design, which considers students with lower motor abilities. For cognitive engagement, students demonstrated strong focus and attention to the activities, though concentration scored slightly lower, possibly due to the demands of end-of-semester assignments and exams. Overall, students were most engaged emotionally and cognitively, while physical engagement varied depending on individual comfort levels with circuit building and hands-on tasks.

The results from the post-survey, shown in Figure 9, show that the interest in fluid power remained relatively stable with an initial high interest level (3.88 out of 5). Since their interest was already well-developed, only slight further increases were observed post-intervention (from 3.88 to 3.89). This minimal shift can be attributed to the participants being junior and senior mechanical engineering technology students who voluntarily enrolled in the fluid power course as an elective, suggesting a preexisting interest in the subject and contributing to the stability in interest levels. Conversely, perceived competence, initially lower, showed greater room for improvement and thus increased notably after hands-on experience (from 3.57 to 4.00).

Figure 10 illustrates the strongest correlations from the Lab Kit Survey, showing relationships between key engagement factors. The highest correlation (corr. = 0.90) was between enthusiasm for using the lab kit and full concentration on activities, indicating that more enthusiastic students remained highly focused. A strong correlation (corr. = 0.85) linked effort in lab tasks with learning enjoyment, suggesting that students who put in more effort found the experience more rewarding. Similarly, attention to activities strongly correlated (corr. = 0.83) with a sense of fulfillment, reinforcing that focused students felt more accomplished.

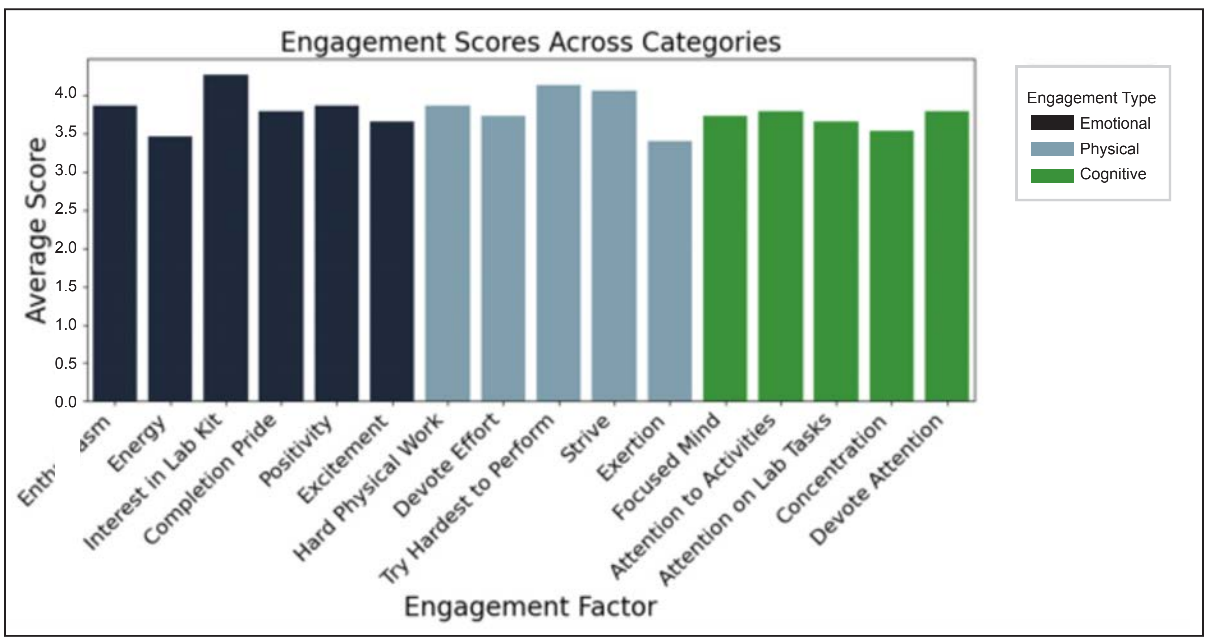

Figure 8. Engagement scores (out of 5) across different categories (Emotional, Physical, and Cognitive).

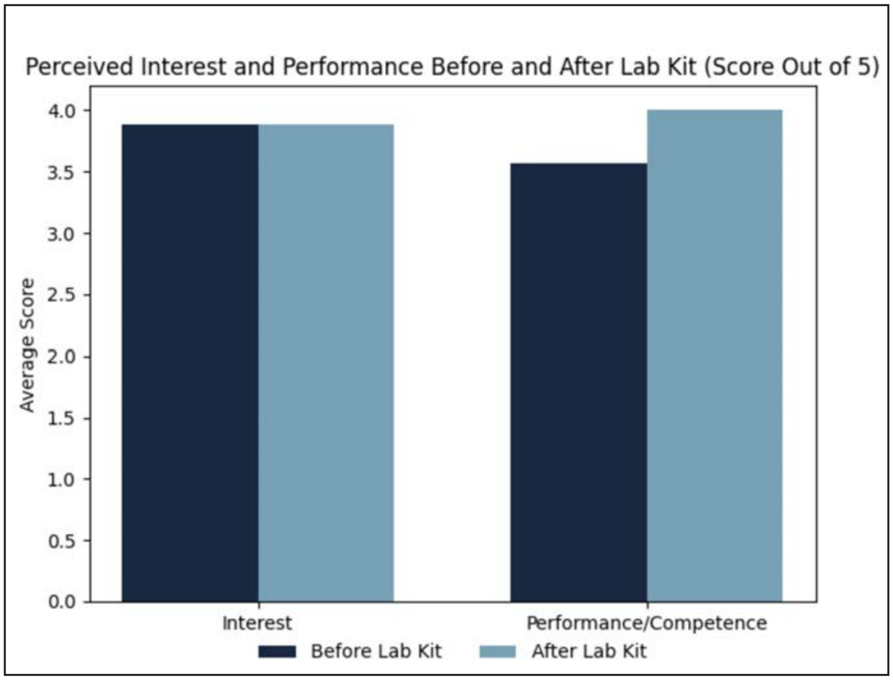

Figure 9. Comparison of students' perceived interest in fluid power and performance/competence before and after using the lab kit.

5. Discussion

The lab kit was developed to address limited hands-on opportunities in pneumatic systems within fluid power education. Unlike simulations, it provides direct interaction, reinforcing technical skills and problem-solving abilities through structured, cost-effective modules. By bridging theory and practice, the kit offers students real-world application experience in a way that traditional classroom methods cannot. Survey results confirm that the lab kit enhances student engagement, perceived competence, and interest in fluid power. Students who were enthusiastic about using the lab kit demonstrated higher concentration, and those who invested effort reported greater learning satisfaction and a stronger sense of accomplishment. While interest in fluid power remained relatively stable, perceived competence significantly improved, indicating increased confidence in applying fluid power concepts. These findings reinforce the importance of hands-on learning in motivating students and improving conceptual understanding. Additionally, the modular design enhances curricular flexibility, allowing instructors to adapt it to different instructional levels and expand learning objectives. The kit also promotes collaborative problem-solving, fostering teamwork and technical skills applicable to engineering and industry settings.

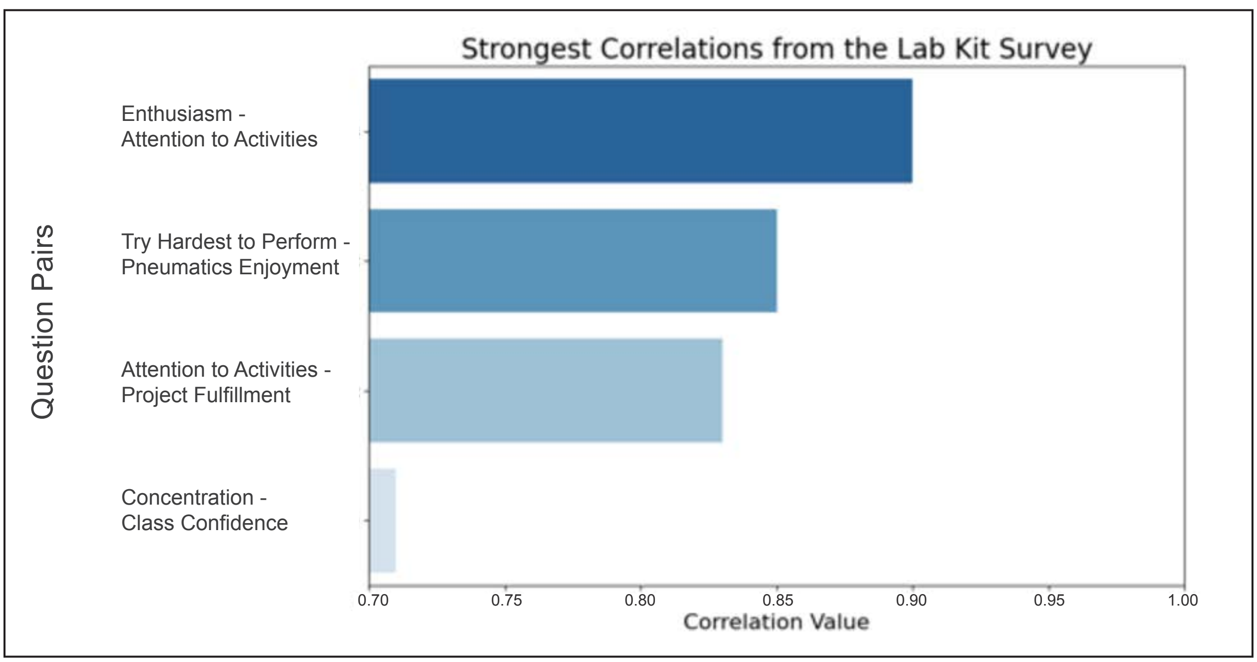

Figure 10. Strongest correlations identified in the Lab Kit Survey.

6. Conclusion & Future Work

This study presents an affordable, modular lab kit designed to enhance fluid power education through hands-on learning in pneumatic systems. It addresses gaps in traditional curricula by providing practical experience in actuation, control, data acquisition, and sensor calibration. The structured yet flexible design allows students to bridge theory and real-world applications, while also supporting hydraulic systems education. As a cost-effective alternative to conventional lab setups, the kit increases accessibility for resource-limited institutions. Survey results confirm its positive impact on student engagement, interest in fluid power, and perceived competence. While the initial results demonstrate the lab kit's potential, future iterations should focus on design refinements, module enhancements, and addressing limitations identified through student feedback. Enhancing survey methods and incorporating quantitative performance metrics will provide deeper insights into learning outcomes. Further studies with larger sample sizes and extended implementation periods are necessary to validate findings and optimize their effectiveness. Additionally, testing the kit's applicability in other fluid power courses at different institutions could support its adoption as a standardized educational resource.

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Mohammed Metwaly

Mohammed Metwaly is a Ph.D. student at Purdue University, developing immersive AR/VR systems that analyze user behavior through interactive experiences and visual data. His work integrates real-time data collection, automated analysis pipelines, and secure web-based platforms to advance understanding of human interaction in virtual environments.

Farid El Breidi

Dr. Farid El Breidi is an Assistant Professor in the School of Engineering Technology at Purdue University. His research focuses on digital fluid power, digital reality, and engineering pedagogy. He is the PI on several projects funded by the National Science Foundation on the use of digital technologies in engineering applications.

Dr. Jose M. Garcia-Bravo

Dr. Jose M. Garcia-Bravo is an Associate Professor in the School of Engineering Technology at Purdue University. He has a special focus on fluid power (hydraulic and pneumatic systems) research and instruction, and smart manufacturing.

Career Trajectories in a Technology Management Program: Alumni Perspectives

Jinhua Zhao, Noemi V. Mendoza Diaz and Rufino Oregon

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Abstract

Technology Management (TCMG), as part of the STEM spectrum, has gained increasing interest within the engineering technology community. In the early 2000s, a TCMG program was launched at a Southwestern institution within the College of Education. In 2021, the program transitioned to the College of Engineering. Even before this transition, graduates of the program experienced significant changes in curriculum, faculty, and institutional alignment, with the first full-time, tenure-track faculty members being recruited in 2018. To understand the effects of these changes, a two-phase study was conducted to assess how alumni perceive the program's impact on their career trajectories. Utilizing Career Theory and informed by relevant research on undergraduate program's effects on graduates, two research questions were investigated: (1) How do graduates of a technology management program perceive their career trajectories? and (2) How are these perceptions related to their college experiences? The first phase of the study, involving an online survey of 75 graduates, was published in 2020. The second phase is discussed here. This phase involved follow-up interviews with ten alumni from the original participant pool, who represented diverse backgrounds in terms of years since graduation, race, ethnicity, and gender. The interviews, analyzed qualitatively, resulted in seven key themes: (1) Choice of Program, (2) Career Trajectory, (3) Career Advancement, (4) HRD-related coursework, (5) TCMG-related coursework, (6) the Management Minor, and (7) Critical Success Factors. The findings align with existing literature, offering insights into how graduates navigate evolving academic environments and providing recommendations for how universities can better support students pursuing careers in engineering technology.

1. Introduction

With the growing demand for science, technology, engineering, and mathematics (STEM) professionals, STEM majors have become increasingly popular in colleges and workplaces. According to the U.S. Bureau of Labor Statistics (2024), the STEM job market is projected to grow by 10.8% from 2022 to 2032. The United States will need over one million additional STEM workers in the next decade, prompting colleges to aim for a 34% annual increase in enrollment for STEM undergraduate programs (Jewett & Chen, 2022). The demand for these professionals highlights the importance of tracking career trajectories and improving career outcomes for STEM graduates. Prior to the COVID-19 outbreak, the call to reimagine STEM education coincided with a decline in college enrollment. In the post-COVID era, redefining college education and preparing a skilled and talented STEM workforce are critical challenges for universities (Mendoza Diaz et al. 2020). This study aims to explore how the training provided by universities contributed to students' career trajectories and success. It also seeks to explore the factors influencing students' major choices, their experiences with the courses and activities offered by a technology management (TCMG) program at an R1 institution in the Southwest, and their suggestions for enhancing the program to better support their career trajectories.

The research questions guiding this investigation are:

(1) How do graduates of a technology management program perceive their career trajectories?

(2) How are these perceptions related to their college experiences?

2. Theoretical Framework

To achieve our goals, we framed our study in career theory, success, and competencies. Career theory, as a branch of Human Resource Development, explores how professionals perceive and achieve career success. Career success is defined as "a positive outcome of a career experience and a process of achieving work-related goals" (McDonald & Hite, 2023, p. 27). Within the broader scope of career theory, several predictors of career success have been identified, including:

- Human capital (e.g., education, training, and work experience)
- Social capital
- Organizational sponsorship
- Socio-demographic variables (e.g., gender, race, and age)
- Stable individual characteristics (e.g., personality, locus of control, cognitive ability)
- Structural contextual factors (e.g., environmental or societal influences such as economic conditions, legislation, or education systems)

In addition, the theory incorporates the concept of career competencies as key enablers of success. According to DeFillippi and Arthur (1995), these competencies are categorized as "know-why," "know-how," and "know-whom," which can be understood as follows (see Figure 1):

- Know-why: Self-awareness of interests, values, and motivations
- Know-how: Job-related knowledge and career-relevant skills (e.g., training)
- Know-whom: Career-related networks and relationships that benefit both the individual and the organization.

These concepts directly informed our research design and interview protocol. For example, interview questions encouraged participants to reflect on why they chose the TCMG program (Know-why), how courses, projects, and faculty influenced their skill development (Know-how), and the role networks played in their career progression (Know-who). As with any theoretical framework, Career Theory offers a rationale for interpreting the results presented here. It provides a structural foundation for examining how graduates understand and navigate their career trajectories. Additionally, our study was framed within existing literature related to Career Theory and aligned with program characteristics.

3. Literature Review

Career Theory has gained traction in engineering technology literature, reflecting a growing interest in understanding how students conceptualize their professional paths. Several studies underscore the importance of developing specific career competencies—namely "know-how" (practical skills and experience), "know-why" (motivation and purpose), and "know-whom" (social and professional networks)—as students navigate from education to employment. Research has explored areas such as student awareness (Dyrud, 2022), engagement through co-curricular experiences (Yanik et al., 2021), and the influence of industry partnerships on skill development and workforce preparation (Sergeyev et al., 2019). These studies offer concrete insights into how academic programs shape engineering technology students' professional identity and readiness.

Academic institutions play a vital role in building these career competencies. Internships, for example, are essential for developing "know-how" by providing real-world experience and translating theoretical knowledge into practice. Prior research highlights that internships improve students' job readiness and self-efficacy, particularly in STEM disciplines (Sawyer, 2017; Matusovich et al., 2019; Powers et al., 2018; Sriraman et al., 2016). Internships also foster "know-why" by helping students clarify their professional goals through applied learning. This study builds upon this work by examining how the TCMG program's internship requirement supports the development of both skills and purpose.

Mentorship and advising are instrumental in cultivating "know-whom" competencies, helping students access networks that shape their academic and professional journeys. Strong advising relationships guide course and career planning (Khali & Williamson, 2014; Laghari & Khuwaja, 2012) and improve retention among underrepresented groups (Belser et al., 2017; Uddin, 2019; Canaan & Mouganie, 2023; Primé et al., 2015). A longitudinal study by Fadigan and Hammrich (2004) emphasized staff availability as a major factor in student persistence. Mentorship is

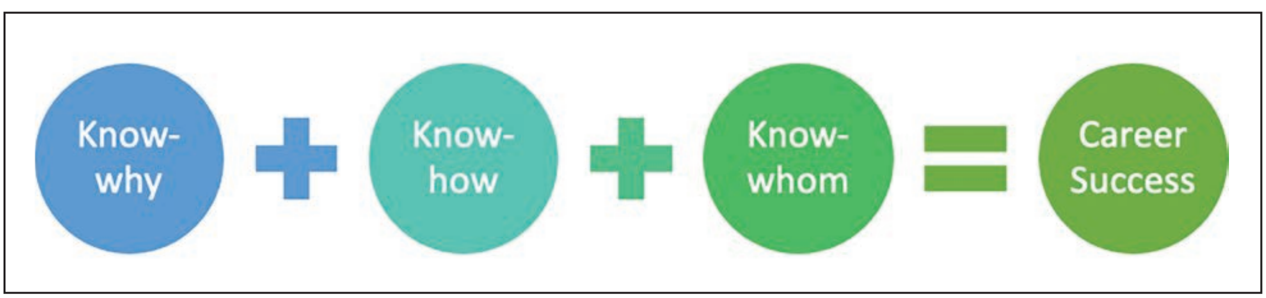

Figure 1. Career Theory Schematic based on DeFillipi and Arthur (1994).

especially important for students navigating systemic barriers: for instance, San Miguel and Kim (2015) found that multiple mentors significantly benefited Latinas in STEM, while Yanik et al. (2021) reported improved self-efficacy and engagement tied to mentorship. In engineering technology, Kaul et al. (2015) and Kaul (2019) highlighted how mentoring within undergraduate research fosters vertical integration, contributing to both retention and a stronger professional identity.

Project-Based Learning (PBL) further supports "know-how" by integrating hands-on experience, teamwork, and critical thinking. Meta-analyses by Hidayat et al. (2024) and Zhang and Ma (2023) confirm that PBL improves academic performance, attitudes, and higher-order thinking, particularly when implemented over 9–18 weeks with small student groups. Effective teamwork—a core element of engineering—requires shared goals, communication, and mutual accountability (Chowdhury & Murzi, 2019; Huang, 2021). Despite its benefits, PBL's impact on technology management remains underexplored. This study addresses that gap by analyzing how PBL in the TCMG program strengthens career readiness.

Finally, connecting learning to employment remains a persistent challenge. Graduates often face the "work experience paradox"—the expectation that they possess prior experience for entry-level jobs, even though few opportunities exist to gain that experience before entering the workforce (Perrone & Vickers, 2003). These unrealistic demands, combined with limited guidance, can lead to anxiety, stress, and feelings of unpreparedness. Abulhassn and Roberts (2021) echoed these concerns, calling for greater engagement with professionals and the inclusion of more job-readiness content. This study investigates how the TCMG program integrates internships, mentorship, PBL, and advising to equip students with the "know-how," "know-why," and "know-whom" competencies essential for a successful career transition.

4. Methodology

4.1Research Setting

The year 2021 marked an important event for a technology major in a Southwestern institution. As part of the restructuring of the university, this technology program transitioned from the College of Education to the College of Engineering becoming an Engineering Technology major. Before this move, the program was part of the Human Resource Development Department and contained seven courses in this discipline. Other seven technology-oriented courses were revised and established by the current faculty keeping a minor in management from the University's Business School. The program started graduating students in the late 2000s, yet it did not house any tenure track faculty until 2018. With all these changes occurring, the need for a study that investigated the career trajectories of its graduates as well as the college experiences influencing these trajectories became critical. This study investigated graduates' perceptions prior to the college transition and serves as a baseline for future studies that investigate the effects of this transition. This manuscript presents the second phase of a larger research project sponsored by the institution's Office of Diversity. The overarching goal of the project was to explore the connections between pre-college experiences and graduates' career paths, with a particular focus on the experiences of underrepresented minority groups.

4.2 Research Design

To meet both the programmatic needs and the sponsor's goals, both of which were aligned, a mixed-methods approach was employed. Mixed-methods designs integrate qualitative and quantitative data to provide a more comprehensive understanding of the phenomenon of interest (Creswell & Clark, 2018).

Because the quantitative and qualitative components of our study occurred sequentially rather than concurrently, and because the first phase informed the second, the research design qualifies as a sequential mixed-methods study. The first phase (quantitative) involved an online survey, while the second phase (qualitative) consisted of interviews with selected participants whose survey responses warranted further exploration.

The initial phase recruited 75 graduates from the TCMG program to complete an online survey comprising both closed- and open-ended questions. The survey addressed: (a) factors influencing participants' careers after graduation, (b) perceptions of their college experiences, and (c) suggestions for program improvement. The findings from this first phase were published in 2020 (Mendoza Diaz, 2020).

The second phase, presented in this manuscript, consisted of follow-up semi-structured interviews with a subset of the original 75 participants. This phase aimed to deepen our understanding of how participants perceive their career trajectories and how they connect their professional experiences to the preparation they received in the TCMG program.

The research design for this phase employed content analysis, a method that combines thematic analysis with frequency counts, making it a form of mixed-methods research in its own right, though still considered interpretive and qualitative in nature. As described by Teddlie and Tashakkori (2003) and Sandelowski (2003), this approach is often referred to as the quantification of qualitative results. Content analysis enables valid inferences through coding, allowing large volumes of text to be categorized into key content areas. These areas may be generated deductively using a predefined coding system, inductively from the data itself, or through a combination of both (Weber, 1990). In the fields of technology and engineering education, content analysis has been widely applied, for example, by Pawley et al. (2016) in gender studies and by Chou and Chang (2010) in engineering education research.

The responses to the online survey (first phase) served as the foundation for both the interview protocol and the initial codebook, which was further refined during the interviews and subsequent data analysis (see Appendix). Purposeful stratified convenience sampling, a technique aimed at ensuring representation from as many groups in the population as possible, was employed (Creswell, 2021). This approach targeted all minority participants in the sample (n = 31), including all female participants (n = 10), all Hispanic participants (n = 20), and students from diverse racial and ethnic backgrounds (n = 11). For white male participants, individuals were selected to reflect diversity in age and years since graduation. A total of 10 participants agreed to take part in the second phase, with demographic details presented in Table 1 and age information shown in Table 2. Table 3 provides job positions of participants at the time of the interview.

4.3 Data Collection and Interview Protocol

An interview protocol was designed to collect participants' responses, enabling the exploration of the research questions (see Table 4).

Figure 2 presents a logic model illustrating the links between the research questions and the developed interview questions. As mentioned earlier, the interview questions were developed based on participants' responses from the first phase (online survey)—for example, question 7. They were also shaped by the research questions and grounded in

Table 1. The demographics of the participants.

	White/ Non-Hispanic	African-American/ Non-Hispanic	White/ Hispanic	Multiracial/ Hispanic	Total
Female	2	1	0	1	4
Male	3	1	2	0	6
Total	5	2	2	1	10

Table 2. Age and years after graduation.

Age	22	23	25	25	26	27	30	31	33	39
Years after graduation	1	0	2	3	4	7	8	9	10	10

Table 3. Job position of participants.

Participant 1	Business Analyst
Participant 2	Cybersecurity Analyst
Participant 3	Technology Director
Participant 4	Infrastructure Architect
Participant 5	Cybersecurity Product Manager
Participant 6	Systems Administrator
Participant 7	Cloud Systems Engineer
Participant 8	System Analyst
Participant 9	Systems Engineer
Participant 10	Manager in a centralized IT organization

Table 4. Interview protocol.

	Interview Questions
1	Describe your career trajectory after graduation. What do you do in your job?
2	How did you grow in your career? What learning activities have you been engaged in?
3	Did your college degree help you in your current career?
4	How do you associate your college experience with your career?
5	Does the course selection matter?
6	What attracted you to TCMG?
7	Advice to incoming students? Or According to your responses to the online survey, you have certain recommendations for the Technology Management Program. Can you elaborate on those recommendations?
7a	How are these perceptions related to your college experience, translated into strengths and weaknesses of the program?
8	In your survey response, you listed XXXX factors that impacted your career negatively or positively after graduation. Can you please elaborate?
9	How do you define a career?
10	For minority students: As a minority in the TCMG program, how would you say your experience was different (if any) from the majority population?

the theoretical frameworks guiding this study: career theory and the concept of career success.

4.4 Data Analysis

We performed content analysis based on predefined and emerging themes, along with their associated frequencies. Frequency counts reflect the importance participants assign to the phenomenon under investigation. Each participant's statement was treated as an independent unit of analysis, allowing for an unbiased assessment of how often specific categories were mentioned (Stemler, 2001).

Based on methodological norms of qualitative inquiry and content analysis (Miles & Huberman, 1994; Strauss & Corbin, 1997), interview transcripts were coded systematically under different categories. With the help of the literature review and the results of the first phase of the study, the research team created an initial codebook that served as the basis for the categories. The codebook was iteratively revised and the last version of this codebook can be consulted in the appendix.

The codebook includes seven themes, including Choice of Program, Career Trajectories, Career Advancement, HRD-related Coursework, TCMG-related coursework, Management Minor, and Critical Success Factors (for Program), and thirty subthemes that will be described next.

Using the initial codebook, each transcript was manually coded by two members of the research team using Microsoft Excel to organize and track themes. To promote validity and reliability, the study used Inter-rater reliability (IRR) to check coding results and evaluate how coders agreed (Holsti, 1969; Trochim, 2006).

$$IRR = \frac{2 * number\ of\ agreements}{Juger\ 1st\text{'}s\ coding\ number + Juger\ 2nd\text{'}s\ coding\ number}$$

After comparing the coding and frequency counts of three transcripts by two coders, the initial inter-rater reliability (IRR) was relatively low at 67%. In behavioral science, an agreement of at least 80% is typically recommended (McHugh, 2012). Much of the disagreement stemmed from differing interpretations of the codebook. As part of the qualitative inquiry protocol, discussions, clarifications, and codebook revisions were undertaken, resulting in an improved IRR of 88%. For example, under the theme "Career Advancement," a subtheme titled "Certifications Supported On-the-Job" was added to better capture this aspect of career progression and reduce overlap with other themes.

To ensure trustworthiness, this study incorporated peer debriefing and audit trails. The interviewers had significant experience in qualitative research, and peer debriefing occurred during weekly research group meetings, where ideas and interpretations were analyzed, discussed, and contrasted. The principal investigator (PI) documented all discussions in meeting minutes, stored them on an electronic shared drive, and included communications with participants, referring to them when relevant. Transferability—defined as the "researchers' responsibility to provide the

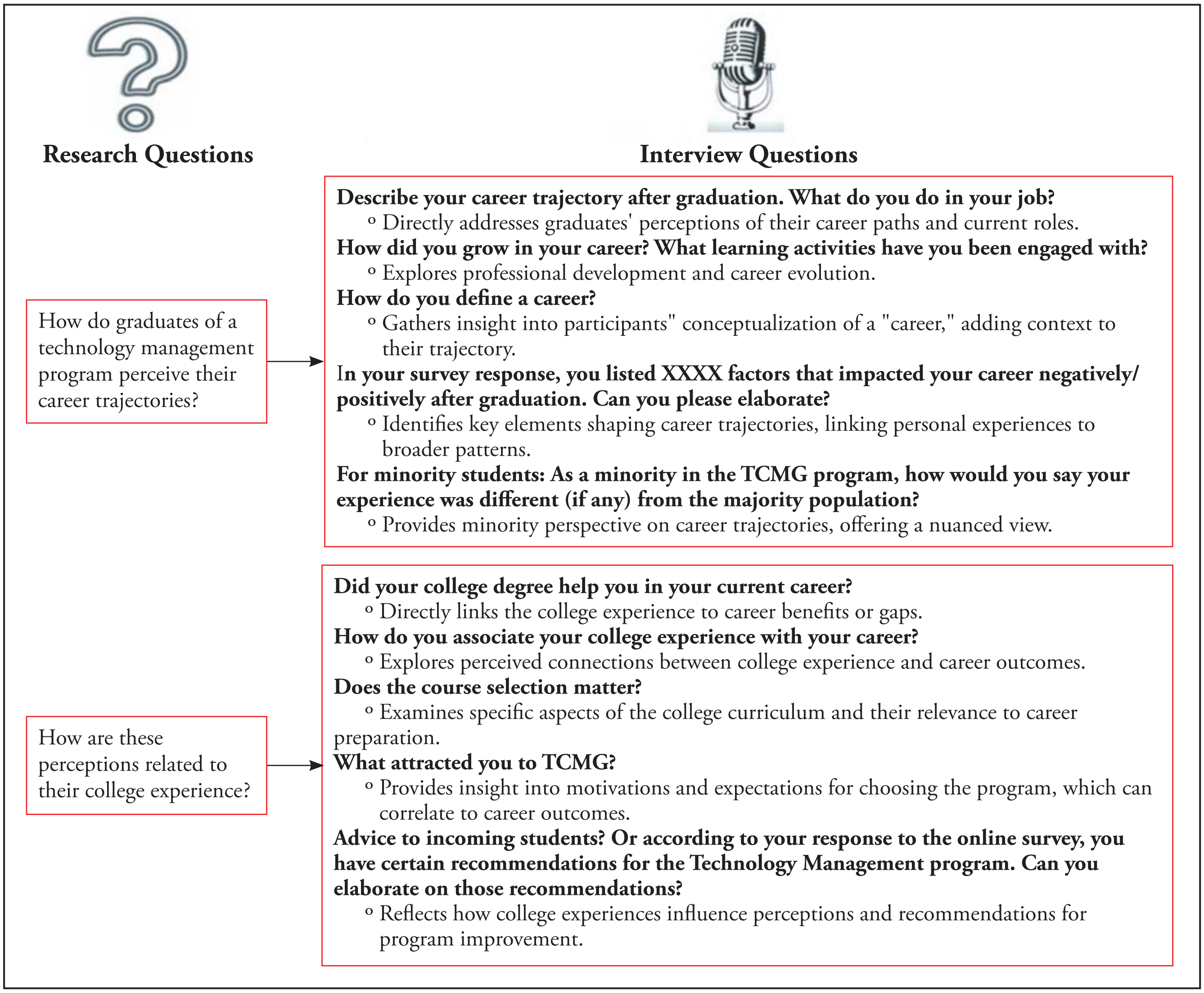

Figure 2. Logic model showing the links between research and interview questions.

database that makes transferability judgments possible on the part of the potential appliers"—is ensured by describing the study's setting and the specificities of the case presented (Lincoln and Guba, 1985).

5. Results

This study explored students' perceptions of their career path and their associations with college experiences. Using a thematic analysis approach, 205 student responses were categorized into 7 themes and 30 subthemes, allowing for a structured interpretation of career perceptions and academic experiences. Since answers to the two research questions were closely related, their findings are presented together.

Table 5 presents the seven general themes along with their definitions. Career Advancement was the most frequently mentioned theme during the interviews, highlighting students' focus on the factors that support job attainment and workplace progression, such as internships, on-campus jobs, mentors, networking, self-directed learning, and certifications. The second most common theme was Critical Success Factors for both the program and the students, which included elements like faculty, courses, project-based assignments, and alumni feedback. The least mentioned theme was Management Minor, reflecting students' attitudes toward the Business School courses and the minor itself.

As shown in Table 6, each theme included a varying number of subthemes. Within the "Choice of Program" theme, the most frequently mentioned subtheme was students' interest in learning and working with technology as their primary reason for choosing the major. Notably, seven out of the ten students in the study transferred to the TCMG program from other majors, primarily engineering. This sug-

Table 5. The results of themes.

Themes	Definition	Frequency
Choice of Program	The factors/experiences for choosing TCMG	30
Career Trajectory	The current career experience	30
Career Advancement	The factors helping with getting jobs and advancing	51
HRD-related coursework	The attitudes toward HRD courses	15
TCMG-related coursework	The attitudes toward TCMG courses	34
Management Minor	The attitudes toward Mays courses	5
Critical Success Factors	The factors promoting the success for programs and students	40

Table 6. Subthemes and codes.

Themes	Subthemes Codes and Frequency Counts
Choice of Program	Wanted to do/started in Engineering (n=9)
	Interest to learn technology and work in technology (n=12)
	Some other major to TCMG (n=7)
	TCMG advised/informed by family (n=2)
Career Trajectory	Satisfied with current title/job (n=9)
	Had to work to get where they are (n=6)
	Expected more from the job (n=5)
	Age affected negatively (interpret with care) (n=2)
	Gender affected negatively (interpret with care) (n=8)
Career Advancement	Participated in internship (n=11)
	Internship helped get job (n=5)
	On-campus job helped (n=2)
	Networking helped (n=4)
	Alumni network (recognition, self-endorsement) (n=6)
	Mentor helped (n=5)
	Learning/self-directed approach utilized (n=8)
	Certifications on-the-job supported (n=10)
HRD-related Coursework	Learned from them (n=7)
	Unnecessary (n=6)
	Neutral perception (n=2)
TCMG-related Coursework	Took technology courses on neighbor college campus (n=3)
	More technical classes needed (n=4)
	Happy with the coursework (n=27)
Management Minor	Immediately applicable to current career (n=2)
	Helpful in the long term (n=3)
Critical Success Factors	The importance of TCMG faculty (n=4)
	Widen course selection range (future) (n=5)
	More project-based assignments (n=7)
	Promotion and public communication (n=2)
	Alumni feedback (n=22)

Table 7. The examples of recommendations as part of the critical success factors.

The importance of TCMG faculty (n=4)	There were a few professors who I would say had helped. I couldn't off the top of my head remember their names but that kind of helped me. {In many cases, they helped} gain a little more self-confidence of what I was capable of doing.
Widen course selection range (n=5)	My focus is more on the data scientist and business analysis side. I feel like I wasn't fully exposed to the various opportunities the major can offer. Instead of having four or five classes that just touch on the subject, I think it would be more beneficial to focus deeply on it. Perhaps we could really explore the different paths available within the major, rather than just giving us a surface-level introduction.
More project-based assignments (n=7)	I like that a lot of the classes were just focused on working in the lab with your peers figuring out how to build the systems and figuring out how to solve all these problems in order to create real solutions in real-world applicability.
Promotion and public communication (a selling point) (n=2)	I think students limit themselves as to what their opportunities really could be. Usually, they lock themselves too specifically into exactly what they want to do. I would better sell the entire program to a recruiter, than come up saying, I want to be a desktop support person; I get that a lot. Being able to sell the entire program and all of the experiences they get in the program would better sell them to a company.
Alumni feedback (n=22)	Maybe past alumni will also come and speak just to show the current student what you can do with that degree in what's possible

gests that, despite their departure from engineering, they still pursued careers connected to technology. The least mentioned reason for choosing the major was being advised or informed by family members, highlighting the need to increase awareness of this program.

In terms of Career Trajectory, students expressed satisfaction with their current job titles or positions nine times. However, it was mentioned six times that they needed to work harder or acquire more skills to meet job demands. Interestingly, gender bias in the workplace was a recurring theme, mentioned eight times. While some students agreed that women face more challenges, others felt there was no difference between male and female experiences in the workplace. Two participants expressed age bias.

For Career Advancement, participants mentioned completing internships, emphasizing that these internships helped them secure full-time jobs after graduation. Certifications were also seen as essential for career growth, noted ten times by seven participants. Alumni Network connections and personal networks were highlighted as significant factors in their career advancement, along with self-directed learning.

Participants had varied attitudes toward HRD-related coursework, expressing positive views seven times, negative views six times, and neutral opinions twice. Neutral responses indicated that some participants did not have clear comments or experiences with HRD-related coursework. In contrast, for TCMG-related coursework, 'satisfaction with the coursework' was a common sentiment, mentioned twenty-seven times. However, it was strongly emphasized that more technical classes should be added to the program. Regarding the Management Minor coursework, participants shared positive opinions, noting its usefulness in their current or future careers. Overall, TCMG-related coursework received more positive feedback compared to HRD-related and Management Minor coursework.

Finally, the recommendations reflect many aspects of students' college experiences and their perceptions of career paths, therefore we called these recommendations the critical success factors. Alumni feedback and support played a significant role, followed by project-based assignments that align the college experience with job market demands. Participants also emphasized the importance of faculty and course selection, suggesting that, alongside hands-on experiences, the curriculum should include more technology-focused coursework. Table 7 provides examples of these suggestions.

6. Discussion

The results are based on interviews with 10 graduates from the TCMG program who are currently working in related careers. Participants shared commonalities in (a) their reasons for choosing the TCMG program, (b) career trajectories and advancement, (c) perspectives related to HRD and TCMG, (d) experiences with management coursework, and (e) critical success factors for the program. These insights enrich the existing literature on Career Theory and offer practical implications for the design and improvement of technology and engineering programs.

To reiterate, Career Theory identifies six predictors of career success: (a) human capital, (b) social capital, (c) organizational sponsorship, (d) socio-demographic variables, (e) stable individual characteristics, and

(f) structural contextual factors. The themes and subthemes emerging from our findings align with these predictors. For example, within the theme of career trajectory, the subthemes of age and gender—both socio-demographic characteristics—played a significant role in graduates' career experiences. Female participants, in particular, reported challenges related to focused working time, promotion opportunities, mentorship, and workplace setbacks. These findings align with the Career Success framework, which shows women are less likely to report feelings of career success (McDonald & Hite, 2023).

The Career Advancement theme yielded the richest data across all forms of capital utilized by graduates in their professional development. Participants frequently cited the impact of institutional alumni networks. Internships, mentorship, and advising—core elements of both human and social capital—also stood out as key institutional supports. An emerging theme was the critical role of networking. Participants emphasized that professional connections helped them secure internships and jobs post-graduation. Alumni feedback further enhanced academic and career development. Networking, as a form of social capital, was consistently recognized as a powerful contributor to career success and student marketability (DeFillippi & Arthur, 1994; McDonald & Hite, 2023), exemplifying the "know-whom" component of Career Theory competencies.

Regarding coursework, participants consistently favored technical over non-technical training. This preference reflects the know-how competency in Career Theory, emphasizing the value of skill development. Project-based courses, access to faculty support, and opportunities for self-directed learning were cited as instrumental in skill acquisition. For example, one participant described a capstone course focused on real-world problems that provided practical experience in technology management. This emphasis on know-how supports prior research on professional conceptualization, co-curricular experiences, and the value of industry partnerships in engineering technology (Dyrud, 2022; Yanik et al., 2021; Sergeyev et al., 2019).

The know-why competency was reflected in participants' narratives about changing majors. Many cited personal interests, career goals, and family influence as key reasons for transitioning into the TCMG program. Some noted a lack of engagement with traditional engineering coursework, which led to decreased motivation. Family also played a significant role—either directly, through advice on choosing a major, or indirectly, through occupational influence. These factors shaped participants' educational decisions and subsequent career trajectories.

7. Conclusion

In summary, the career choices and trajectories of TCMG program graduates align with Career Theory and existing research on undergraduate technology and engineering programs. The findings demonstrate the importance of fostering students' competencies in knowing "why, how, and whom" — regardless of the academic unit housing the program.

The study is limited by the number and composition of participants, and, as with most qualitative studies, the transferability of results is intended to inform and benefit other programs rather than offer broad generalizations. The implications for practice include enhancing the guidance and mentorship students receive, facilitating internships and industry connections, creating networking opportunities among graduates, and raising awareness of structural barriers faced by women and other demographic groups. The implications for research highlight the importance of conducting more comprehensive investigations into program aspects based on graduates' perspectives. At the time of writing this manuscript, data is being collected to examine students' perceived impacts of the transition between colleges. This study provides a critical baseline for future research efforts.

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Appendix: Codebook

Themes	Subthemes	Description	Quote
Choice of Program	Wanted to do/started in engineering	Talk about why they choose the program and mention they wanted to do engineering	In my case, I actually thought I wanted to go into industrial distribution or engineering technology and turns out I'm not very good at calculus, engineering, math, so those were kind of pushed to the side of it.
	Interest to learn technology and work in technology	Talk about why they choose the program and mention they were interested or wanted to work in technology fields.	I didn't know much about technology but I think it's something that I really enjoy learning about and that I'm really passionate about. And when you bring in diversity. It definitely helps someone feel more comfortable being themselves and learning as much as they can and sharing the ideas with other people.
	TCMG advised/informed by family	Talk about why they choose the program and mention they got advisors from others or were influenced by others.	When I had talked to my now husband. At the time I knew he was in this major and he didn't land in this major to start with. He thinks he started as a math major or something like that. And it took him some time to find his way to tech management. So when I was getting ready to graduate {HS} and getting ready to apply I had asked him straight. I was like what college should I be applying for because this is the stuff I like to do this is why I would like to continue doing. And he's the one that actually ended up saying "hey yeah okay tech management.".

Career Trajectory	Satisfied with current title/job	Mention they are happy and satisfied with current job or title	I love it, it's a great job. I have so many resources to, you know, further my career and develop, it's a great tech company, I love it.
	Had to work to get where they are	Hard to catch or follow others' steps; work harder; they need to learn new things because they did not learn from colleges; learn more	I've worked very hard to get to where I am today, and I think I bring a lot to the table and I'm definitely always willing just to learn something new.
	Expected more from the job	Having more expectations than others	So, yeah I don't want to do like the little simple jobs where I'm just going to work and I'm just doing it for the paycheck. Actually I want to love what I'm doing. I want to, you know, build a career
	Age affected negatively (interpret with care)	Perception of age impacting negatively their professional experience	I feel almost like I have to instill confidence that oh yeah I can do this, and I think a lot of it still goes back to that perception that she's young {talking about how she was perceived} and she really hasn't been here that long.
	Gender affected negatively	Perceptions of gender biases	Well we've experienced with some of the women that we hired that they were always on their phone, and we needed them to be continuously working.
Career Advancement	Participated in Internship	Mentioned of the effect of internships in their advancement	I did internships during summers that weren't part of the coursework required and so I interned as a project management intern. It was in the pharmaceutical company up in X city and then I interned for my official internship in an ecommerce company in Y city.
	Internship helped get job and advance	Mentioned internship helped towards obtaining jobs	It has been and has always treated me really well, I moved up in the company {since internship}. They were bought out by a company called X company, and X company got rid of everyone else except for me. So, it is my knowledge, my expertise and what my skills are that I bring to the table. The only people that they kept were me, and the clientele and that's it. So now I work with X company.
	On-campus job helped	Mentioned how on-campus job helped	Yeah, so I was basically a student and wanted to get some experience. And so I feel like that was the easiest path, that way I could go to school… So yeah I got a lot of experience from being student technicians, I would recommend. I've had students reach out to me and I recommend getting a student technicians are just so they teach you the basics and you can get some hands on experience. So that was very beneficial for me.
	Networking helped	Mention the network of professors, advisor, bosses in the internship, etc.	I'm pretty shocked to find a job next week because I have a network that I have worked on since college. So, absolutely. Yeah, that's great. That's actually how I got the internship connection. Yeah, I'll elaborate on this.
	University Alumni Network (recognition, self-endorsement)	Point out alumni network as factor influencing advancement	A person also went to my university but he got his degree in water management, or something like that. It wasn't in the IT department but he did help me find out about the job.
	Mentor helped	Point out mentors' help to advance in job	So make sure you have mentors who can help you understand how much the waiting time of the system is necessary because sometimes there are policies and things in place but yes, nobody is responsible for your career growth but yourself.

Career Advancement (continued)	Learning/self-directed approach utilized	Mentions self-directed learning	I mean in any kind of technology field, you have to be willing to learn yourself because you know you're not gonna know everything you have to, you know, do it. You have to be self-taught a lot of things because there's not only so much specialization out there.
	Certifications on-the-job supported	Mentions the importance of certification in pursuing jobs or talk about getting certification for jobs	Now one thing I would like to see if I can go back and do it again. I would like one of the requirements to not just be to take the class, but to actually go out and get the certification that be part of the curriculum is that you have to go and take and pass the certification, which would be useful going into the job market to where you have the experience as well as the certification and the degree that would make you a kill shot in my opinion from a resume standpoint.
HRD-related coursework	Learned from HRD	Talk about how and what benefits of classes they got	And so a lot of those human development classes. I think it helped me understand how to be an employee and drive a team to actually deliver something, not just how to do something.
	Unnecessary	Did not feel any benefit from the class content	Two or maybe additional HRD courses that were beneficial but I don't feel like it was necessary because I feel like you guys are just trying to fill it in. Because there was a lot of organization and changes and so, we needed something in our curriculum and so you just didn't have the personnel
	Neutral perception	Talk from both side or mention some pains and gains	And I don't do any of that, I don't do a data analysis of my company {talking about the HRD research class}. So it's not something that applies to me, my career and my workforce. At the moment, it may come in later though, I mean who knows.
TCMG-related coursework	Took Technology courses on a neighboring Campus	Point out another neighboring campus and technology classes	Yes, let me elaborate on the hands-on classes that we took network, network plus, and all the other coding courses we took at the neighboring college.
	More technical classes needed	Emphasized the need to provide more technical classes	I was kind of hoping for more technical classes. A proper term would be more creative. So like the video editing type of courses, I was more interested in the technical courses, relating to software.
	Happy with the coursework	Mention they got a lot from courses and think they are useful	The DevOps course was really beneficial.
Management Minor	Immediately applicable to current career	Contribute to finding jobs due to some skills.	I use HTML because if you're a new hire for example and you need an email. The email was straight HTML, so I took business owner info from the business minor. That's where I learned HTML. All that class is very helpful…The information from that one is extremely helpful. The XML pivot system, so helpful.
	Helpful in the long term	Point out the long term positive effect	I think that the courses that I took, like I said earlier, were extremely helpful in setting that mindset, because yeah there was a lot of stuff especially around project management, business acumen, financial acumen, that I had absolutely no clue about before going into the major.

Critical Success Factors	The Importance of TCMG faculty	Point out faculty is really helpful with being successful	There were a few professors that I would say had helped me. I couldn't off the top of my head remember their names but that kind of helped me. And a lot of cases just gain a little more self-confidence and what I was capable of doing.
	Widen course selection range	Mention they need more varied courses/ there is not wide enough courses for them to choose from	My position is more on the data scientist- business analyst. I feel like I wasn't really exposed to different things you can actually do with the major.
	More project-based assignments	Mention project/capstone/ practice assignment	The capstone course that I had with Dr. X was really beneficial. I like that a lot of the classes were just focused on working in the lab with your peers figuring out how to build the systems and figuring out how to solve all these problems in order to create real solutions in real world applicability.
	Promotion and public communication	Mentioned students need to self-market and present themselves	I think students limit themselves as to what their opportunities really could be. Usually, they lock themselves too specifically into exactly what they want to do… I would better sell the entire program to a recruiter, then coming up saying, I want to be a desktop support person, I get that a lot. Being able to sell the entire program and all of the experiences they get in the program would better sell them to a company.
	Alumni feedback	Alumni help/network/feedback	Maybe past alumni will also come and speak just to show the current student what you can do with that degree in what's possible, and this is confidential.

Jinhua Zhao

Jinhua Zhao is a Postdoctoral Faculty Fellow at the Communication University of China. She holds a Ph.D. in Educational Administration and Human Resource Development from Texas A&M University. Her research centers on education policy, particularly STEM education, examining how educational systems and policies shape students' experiences. She aims to bridge research and practice to promote equity and innovation in STEM pathways.

Noemi V. Mendoza Diaz

Noemi V. Mendoza Diaz, Ph.D., is an Assistant Professor in the Technology Management Program within the College of Engineering at Texas A&M University. Her areas of expertise include computer education and the participation of minorities in engineering. She serves as the faculty advisor for three student organizations: the TCMG Society, the Society of Hispanic Professional Engineers (SHPE), and Latinos in Engineering and Science (MAES).

Rufino Oregon

Rufino Oregon holds a B.S. in Technology Management and is passionate about research in technology, engineering, and education. He has conducted research at TAMU, Rice, and LSU, contributing to data analysis, visualization, and fieldwork. He's co-authored a CS education paper, presented at Rice, and worked with leading scholars using Python, R, and SQL.

The Four Pillars of Manufacturing Knowledge: A Contemporary Perspective on Practical Implementation

John Irwin, Ismail Fidan, Neil Littell, Suzy Marzano, David Labyak, Scott Wagner, Anis Fatima and Amna Mazen

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Abstract

The Four Pillars of Manufacturing Knowledge has undergone a substantial revision to encompass the changing landscape of advanced manufacturing, incorporating concepts such as Industry 4.0, Additive Manufacturing (AM), etc. This revised version of the Four Pillars is aligned with the original purpose to be used by industry and academia to represent the breadth and scope of manufacturing engineering based on accreditation criteria and SME's Body of Knowledge for the Certified Manufacturing Engineer and Technologist (CMfgE and CMfgT). The revised Four Pillars has changes in eleven of the twelve knowledge blocks. The Automated Systems and Control knowledge block, now renamed as Industry 4.0 and Automated Systems and Control, included the most revised topics, with only two remaining unchanged. Process Design is another knowledge block that went through major revisions with the addition of digital manufacturing topics such as: Digital Twin and Computer Aided Process Planning. Overall, this paper presents each of the new and revised topics to gain a better understanding of the implications for ongoing research and education in manufacturing worldwide. Practical examples of teaching methods, as well as laboratory applications, are provided for some of the topics that are most critical to the future of the manufacturing industry.

1. Introduction

The Four Pillars of Manufacturing Knowledge (Four Pillars) was first published in 2011 as a component of the Curricula 2015; A Four-Year Strategic Plan for Manufacturing Education (Jack, Mott et al. 2011). The concept of the Four Pillars includes foundation skills in A) Mathematics and Science and B) Personnel Effectiveness with four major categories: 1) Materials and manufacturing processes; 2) Product, tooling, and assembly engineering; 3) Manufacturing systems and operations; and 4) Manufacturing competitiveness. According to the authors (Mott and Jack 2011), the process of developing the Four Pillars was initiated by the SME through its Center for Education. Since its conception, the Four Pillars have been utilized across the country and internationally as a model for curriculum development for manufacturing engineering and manufacturing engineering technology degree programs (Mott, Bennett et al. 2012), (Mott, Stratton et al. 2012), (Wells 2012), (Nutter, Mott et al. 2013), (Nutter and Jack 2013), (Mott and Jack 2013), (Mott, Bennett et al. 2013), (Ermer 2013), (Plouff, Pung and Jack 2014), (Pung and Jack 2014), (Yip-Hoi and Newcomer 2015), (Doggett and Jahan 2016), and (Littell, Shraim and Sheets 2023).

According to the authors (Irwin, Johnson and Marzano 2022), the process for the Four Pillars revision was first initiated by the SME Manufacturing Education and Accreditation Committee in 2020. Updates to the ABET accreditation standards (ABET 2022) and SME's Body of Knowledge for CMfgE and CMfgT certification programs (SME 2020) preceded the revisions to the Four Pillars. The SME Body of Knowledge added a new category for "Digital Enterprise" focusing on the increasing impact that digital technologies have in manufacturing. It features expanded coverage of topics such as the Industrial Internet of Things (IIoT), data science, digital performance management, artificial and augmented intelligence, machine health/asset optimization, digital twins, and digital threads.

In 2021, a sample population of manufacturing experts from industry, government, and the academy was surveyed from the SME database. The existing twelve blocks of knowledge were presented to those surveyed, with the option for the respondent to either keep, remove, or edit the topics in each. Suggestions for additional topics (missing elements) in each knowledge block were also collected in the survey. SME staff performed data analysis and presentation of the survey results, after which an organized process was used to validate the suggested revisions to the knowledge blocks. Academic, industry, and government expert members from the SME Manufacturing Education and Accreditation Committee reviewed and distilled the survey results into a format to present to the manufacturing community for their input. Workshops were delivered at the 2023 ASEE, SME, and ATMAE conferences to provide feedback on the Four Pillar revisions. An interactive SME webpage was used to collect input from attendees of the conference workshops to refine the topics in each knowledge block further.

The revised version published by SME in 2024 resulted in new or revised topics in eleven of the twelve knowledge blocks. The only knowledge block without changes is Mathematics and Science. The Automated Systems and Control knowledge block, renamed as Industry 4.0 and Automated Systems and Control, included the most revised topics with just two topics remaining unchanged. Process Design is another area that experienced major revisions with topics such as Digital Twin and Computer-Aided Process Planning.

2. Methods

Due to the revisions in accreditation standards, SME's Body of Knowledge for the CMfgE and CMfgT certification programs, and the Four Pillars to include Industry 4.0 advanced manufacturing practices, how can manufacturing curriculum change to impact student understanding and application of these concepts? The answer to this question can assist educators in updating manufacturing program curricula and provide the industry with a clear picture of the knowledge, skills, and abilities (KSAs) of manufacturing graduates.

Each of the revised knowledge blocks in the Four Pillars has advanced manufacturing topics that deserve attention from industry and academia alike. Much can be learned from investigating each of the Four Pillar knowledge blocks to scrutinize the need for revised curriculum, investment in equipment, and/or development of new software in these critical areas.

First, each of the new topics and revised topics in the Four Pillars are described in detail. Next, these topics are analyzed to better understand the advances in technology that have taken place since the original version of the Four Pillars. Finally, the authors will provide practical applications for implementing the advanced manufacturing topics into the curriculum or research.

3. Results

The # 1 "Mathematics and Science" knowledge block has no changes. The # 2 "Personal Effectiveness" knowledge block has five added topics, and others are changed or combined (see Figures 1 & 2).

Knowledge is deleted from this list because it was found to be too general of a term. The added topics are *Emotional Intelligence* (the ability to recognize, understand, and manage your own and other people's emotions), *Diversity, Equity & Inclusiveness (DEI)* (organizational frameworks and practices that promote fair treatment and full participation of all people), *Social Responsibility* (where a person works and cooperates with other people and organizations for the benefit of the community), *Ethics* (moral principles that govern a person's behavior), and *Innovation and Creativity* (process of initiating something new and turning it into practical and valuable solutions) (see Table 1).

The #3 "Engineering Sciences" knowledge block has only two changes. The topic of Electrical Cir-

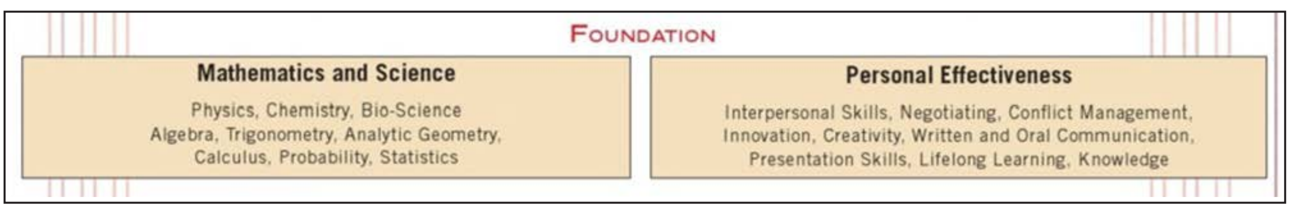

Figure 1. Original Foundation knowledge blocks.

Figure 2. Revised Foundation knowledge blocks.

Table 1. Personal Effectiveness (block 2).

Topic	Changed to	Combined with
Interpersonal Skills	Professional skills - **Interpersonal Skills and Lifelong Learning**	Lifelong Learning
Negotiating	Negotiation **skills**	
Innovation	Innovation **and creativity**	Creativity

cuits/Electronics is renamed to Electrical Circuits/Electronics/*Instrumentation*. Secondly, the topic of *Material Science* is added (see Figures 3 & 4).

The #4 "Material" knowledge block is renamed to "Engineering Materials" that has three deleted topics, which are *Nanotechnology, Foams, and Hybrids* (see Figures 5 & 6). Other topics are incorporated into the new topics (see Table 2), and the *New/Advanced Materials* topic is added, which encompasses the many new alloys possible with laser sintering capabilities. Also, this topic is used to capture a wider range of materials without having to add every new material that is utilized, and to keep it generic in a sense.

The #5 "Manufacturing Processes" knowledge block has one deleted topic, which is *Hand Tool Use and Machine Operating* (see Figures 7 & 8). Other topics are incorporated into the new topics (see Table 3).

The added topics are *AM Processes* (building three-dimensional objects layer by layer from a digital 3D model), *Biomanufacturing* (using biological systems to produce biomaterials for industrial products), *Nano-*

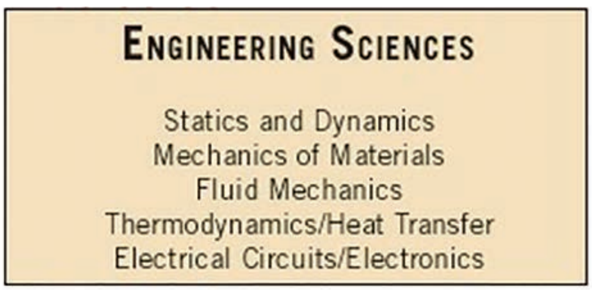

Figure 3. Original Engineering Sciences.

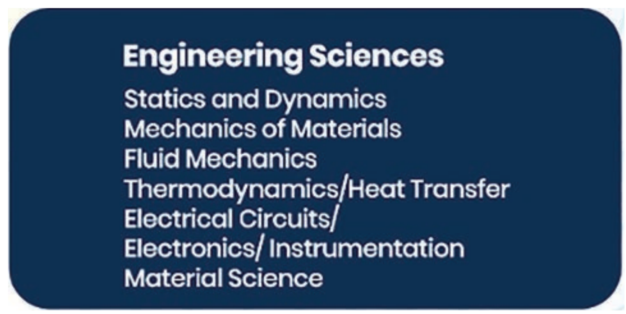

Figure 4. Revised Engineering Sciences

Figure 5. Original Materials.

Figure 6. Revised Engineering Materials.

Table 2. Engineering Materials (block 4).

Topic	Changed to
Natural Materials	**Bio**/Natural Materials

Figure 7. Original Manufacturing Processes.

Figure 8. Revised Manufacturing Processes.

Table 3. Manufacturing processes (block 5).

Topic	Changed to	Moved to
Material Removal	Material Removal/**Subtractive Processes**	
Hot and Cold Forming Processes	**Material** Forming Processes **(bulk, sheet)**	
Bulk and Continuous Flow	**Material Forming Processes** (bulk, sheet)	
Heat Treatment	Heat Treatment/**Heat Transfer or Thermal Processes**	
Fabrication	**Joining and** Fabrication **and Finishing**	
Joining, Welding, and Assembly	Assembly	
Finishing	**Joining and Fabrication** and Finishing	
Material Handling and Packaging		Production System Design

manufacturing (production of nanoscale materials, structures, devices, and systems), and *Non-Traditional Manufacturing* (utilizing energy forms other than mechanical cutting forces, like thermal, chemical, or electrical energy, to remove material or create shapes).

The #6 "Product Design" knowledge block has some topics that have been changed or moved (see Figures 9,10 & Table 4).

The added topics are *Generative Design* (AI-driven iterative process to explore and generate multiple

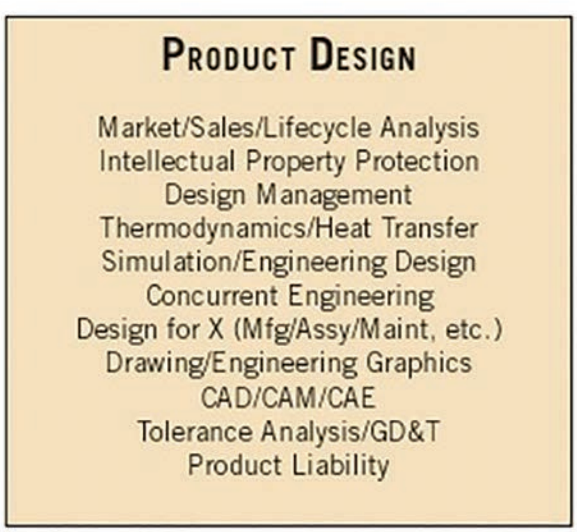

Figure 9. Original Product Design.

Figure 10. Revised Product Design.

Table 4. Product Design (block 6).

Topic	Changed to	Moved to
Simulation/Engineering Design	Simulation/Engineering Design/ **Digital Twin**	
Concurrent Engineering		Quality and Continuous Improvement
Design for X (Mfg/Assy/Maint)	Design for X (Mfg/Assy/Maint/**Rem-fg/Recycling, Sustainability etc.)**	
Thermodynamics/Heat Transfer		Manufacturing Processes

design solutions based on specific constraints for design optimization), Systems Engineering (managing complex systems to ensure they meet requirements and function effectively throughout their lifecycle), *Product Lifecycle Management* (managing a product's journey from initial concept to end-of-life), *LCA tools and ELM* (Life Cycle Assessment tools are software solutions for Engineering Lifecycle Management), and *Design Thinking* (meeting users' needs by understanding them, generating ideas, and testing solutions).

The #7 "Process Design" knowledge block has two deleted topics, which are *Print Reading and Rapid Prototyping* (see Figures 11 & 12). Other topics have been changed and/or combined (see Table 5).

The topics added are *CAD/CAM/CIM/Computer Integrated Manufacturing* (using computer systems to control and integrate all aspects of the manufacturing process), *Model-Based Process Design* (using simulation to understand the behavior of a concept or existing physical system), *Revision Control and Data Management* (system that tracks changes to files over time), *Tool and Equipment Selection* (based on precision required, production volume, and availability of resources) *Process Planning and Development/Computer Aided Process Planning (CAPP)* (encompassing everything from identifying a need to implementing and monitoring the process), *MRL/TRL/New Process/New Product Introduction* (Manufacturing Readiness Level and Technology Readiness Level are frameworks that go hand in hand and used to assess the maturity of a given technology, component or system from a manufacturing perspective).

The #8 "Equipment/ Tool Design" knowledge block has only two changes. The topic of Cutting Tool Design was changed to Cutting Tool *Selection and* Design. The topic added is *Real Time Adaptive Control design for tool condition monitoring*, for exam-

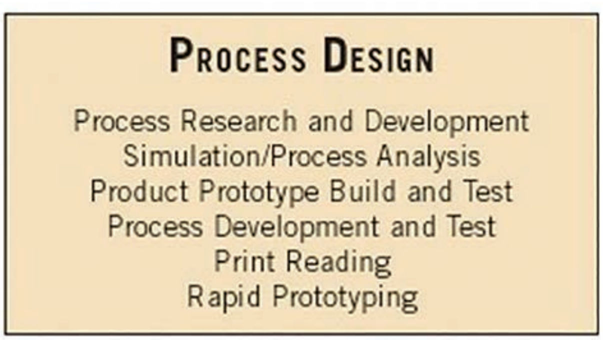

Figure 11. Original Process Design.

Figure 12. Revised Process Design.

Table 5. Process Design (block 7).

Topic	Changed to
Process Research and Development	Process Research **and Design**
Simulation/Process Analysis	Simulation/Process Analysis**/Digital Twin**

Figure 13. Original Equipment/Tool Design.

Figure 14. Revised Equipment/Tool Design.

ple, using in-process data to identify abnormal loads for protecting the cutting tool by lowering feed rate automatically (see Figures 13 & 14).

The #9 "Production System Design" knowledge block has two deleted topics, which are *Infrastructure/Plant Location and Waste Management* (see Figures 15 & 16). Other topics have been changed and/or combined (see Table 6).

The topics added are *ERP/MES* (Enterprise Resource Planning and Manufacturing Execution Systems are used to optimize manufacturing processes by monitoring, tracking, documenting, and controlling throughout the entire production lifecycle), and *Material Handling and Packaging Systems* (the processes and equipment used to move, store, protect, and control materials and products throughout their lifecycle).

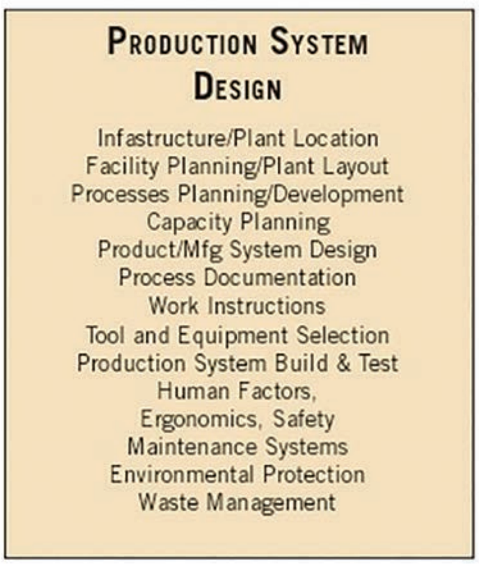

Figure 15. Original Production System Design.

Figure 16. Revised Production System Design.

Table 6. Production System Design (block 9).

Topic	Changed to	Moved to
Product/Mfg System Design	Manufacturing System Design	
Process Planning/Development	Process Planning and Development/**Computer Aided Process Planning (CAPP)**	Process Design
Tool and Equipment Selection		Process Design
Environmental protection	Environmental **Sustainability and** Protection	

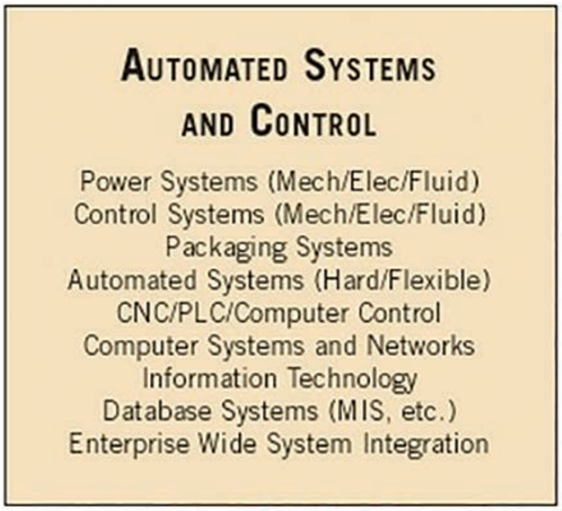

Figure 17. Original Automated Systems and Control.

Figure 18. Revised industry 4.0 and Automated Systems and Control.

Table 7. Industry 4.0 and Automated Systems and Controls (block 10).

Topic	Changed to
CNC/PLC/Computer Control	CNC/PLC/**FMS/Computer Control** Systems
Computer Systems and Networks	CNC/PLC/**FMS**/Computer Control **Systems**
Information Technology	**Informatics** and data analytics
Database Systems (MIS. etc.)	Informatics **and data analytics**

The #10 "Automated Systems and Controls" renamed to "*Industry 4.0* and Automated Systems and Controls" knowledge block has two deleted topics, which are *Packaging Systems*, and *Enterprise Wide System Integration* (see Figures 17 &18). Other topics have been changed and/or combined (see Table 7).

The topics added are *Cyber Physical Systems/Cybersecurity* (addressing vulnerabilities of systems that integrate computing, communication, and physical processes), *Industry Internet of Things* (use of smart sensors, actuators and other devices interconnected to enhance industrial processes), *Mechatronic*s (integration of mechanical, electrical, and computer systems to create intelligent machines and automated processes), *Artificial Intelligence and Machine Learning* (allowing machines to learn from data without being explicitly programmed), and *Machine Vision* (using cameras to interpret images with algorithms to perform tasks like automatic inspection).

Even though not named individually, robotics is an integral part of the automation and controls knowledge block. Robotics is a method of implementing the manufacturing processes and automation systems described. For instance, *Machine Vision* is a method commonly used in a robotic work cell to improve efficiency, but can also be used in conjunction with conveyor systems or other material handling devices. As described by authors (Ma and Pecen 2024) the use of a robotic arm can be incorporated into an undergraduate course to incorporate experiential learning of industrial robotics. When the topic of Mechatronics is used in the Four Pillars, it is assumed that robotics is included as a major component of that system.

The #11 "Quality and Continuous Improvement" knowledge block has two deleted topics that are *Statistical Control Methods and Problem Analysis & Solving Integration* (see Figures 19 & 20). Other topics have been changed and/or combined (see Table 8).

The topics added are *Problem Solving and Root Cause Corrective Action* (identifying, analyzing, and addressing the underlying causes of problems to prevent recurrence), and *Quality Management Systems (QMS),* which document an organization's processes/procedures that implement policies to reduce waste, increase efficiency, and improve customer satisfaction.

The #12 "Manufacturing Management" knowledge block has three deleted topics, which are *Global Competition, Organizational Design and Management*, and *Education & Training* (see Figures 21 & 22). Other topics have been changed and/or combined (see Table 9).

The topics added are *Competitive Analysis Including Intellectual Property* (understanding competitor's

Figure 19. Original Quality and Continuous Improvement.

Figure 20. Revised Quality and Continuous Improvement.

Table 8. Quality and Continuous Improvement (block 11).

Topic	**Changed to**
Capability Analysis	**Process** Capability Analysis
Metrology	Metrology **and Instrumentation**
Continuous Improvement/Lean	Continuous Improvement **and** Lean **Mfg**
Customer and Field Service	Customer **Focus**
Customer and Field Service	**Consumer and** Field Service
Factor Analysis (DOE/Correlation)	**Design of Experiments** (DOE)

Figure 21. Original Mfg. Management.

Figure 22. Revised Mfg. Management.

Table 9. Manufacturing Management (block 12).

Topic	Changed to
Strategic Planning	Strategic Planning **Including: Social, Environmental, Governance, and DEI**
Social Responsibility	Strategic Planning Including: **Social**, Environmental, Governance, and DEI
Project Management	**Leadership** and Project Management
Labor Relations	**Workforce Development** – Personnel Management/**Labor Relations**
Personnel Management	**Workforce Development – Personnel Management/**Labor Relations

IP assets to make strategic decision-making and innovation based on their strengths, weaknesses, and potential threats), *Risk Management* (recognizing potential problems, hazards, or uncertainties that could arise within an organization or project), *Problem Analysis and Solving* (investigating the nature of a problem, its causes, and potential impacts), and *Knowledge Management* (capture and reuse) which involves capturing, organizing, sharing, and reusing knowledge to improve decision-making.

4. Discussion

Apart from the Mathematics and Science knowledge block, all others have new or revised topics. The *Automated Systems and Control* knowledge block, renamed as *Industry 4.0 and Automated Systems and Control*, included the most revised topics, with just two topics remaining unchanged. *Process Design* is another area that has experienced major revisions with topics such as *Digital Twin* and *Computer Aided Process Planning*. Therefore, it is most appropriate to provide practical applications for implementing these topics into the curriculum or research.

Laboratory facilities at higher education institutions need to be transformed into places where students can learn both the traditional manufacturing processes in addition to analyzing data gathered from sensors installed on equipment. Options are typically limited for adding new courses in 2-year and 4-year undergraduate programs or graduate degrees, but enhancements can be made to existing courses to implement the automation and controls aspect of manufacturing.

As described by the authors (Labyak and Wagner 2024), a traditional foundry can be transformed to perform real-time monitoring of material temperatures during casting, rolling, forging, or stamping processes by installing temperature or force sensors and digital cameras to record and timestamp the process to optimize performance and reduce variation. Furthermore, the collected data can enable the development of process emulators to simulate the steps of a process before the actual production begins to increase efficiency through intelligent routing (see Figures 23 & 24).

Extrusion is a manufacturing process that is common to a foundry, which can also benefit from im-

Figure 23. Wireless temperature display module and wireless probe.

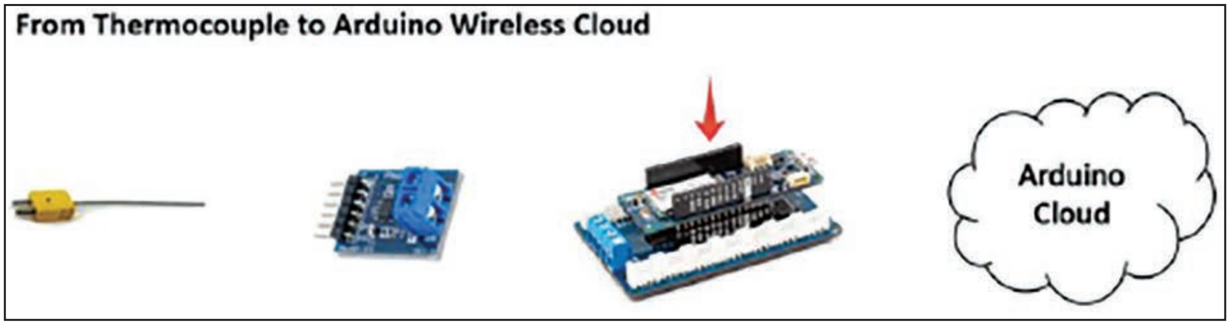

Figure 24. Mold temperature data acquisition using Arduino with wireless capabilities.

plementing pressure and speed controls. Adding the sensing of exiting extruded material temperature can be done with an infrared pyrometer to provide feedback as well as data collection for optimization.

A Digital Twin can be developed to replicate any equipment or process, enabling real-time monitoring and analysis. In a traditional machine shop, Digital Twins can be created for CNC machines and AM systems using computational methods, including artificial intelligence, to enhance energy efficiency, tool wear prediction, preventive maintenance, and product quality management (see Figures 25 & 26).

For example, a Digital Twin can be implemented using Azure Digital Twin Explorer and Azure 3D Scene, both accessible through the Azure Portal (portal.azure.com) with an Azure for Students subscription, which offers $100 in free credit for 12 months. This setup allows for remote monitoring and control of AM equipment via a smartphone or other devices, helping to detect overheating or malfunctions early and prevent material waste and downtime.

The Digital Twin curriculum revisions described here were added to a course offered in the spring semester 2025, renamed as *Industrial Digital Twin Systems*, and changed from the previous course name of *Industrial Systems Simulation*. The previous version was focused on creating simulation models of various industrial systems to analyze and experiment with characteristics of real-life systems for the purpose of engineering process improvement and production. The revised course meets the original course objectives but with principles and architecture of Digital Twins used to optimize systems using real-time data, enhancing decision-making, and operational efficiency in smart industrial environments. The course evaluation and responses from students after implementation of the course revisions were very positive. The end of the course evaluation had 16/16 (100%) response rate. Using a scale of 1-5 from “1=Strongly Disagree” to “5=Strongly Agree”, the average of the seven questions was 4.16, indicating a good level of satisfaction following these course revisions. Chal-

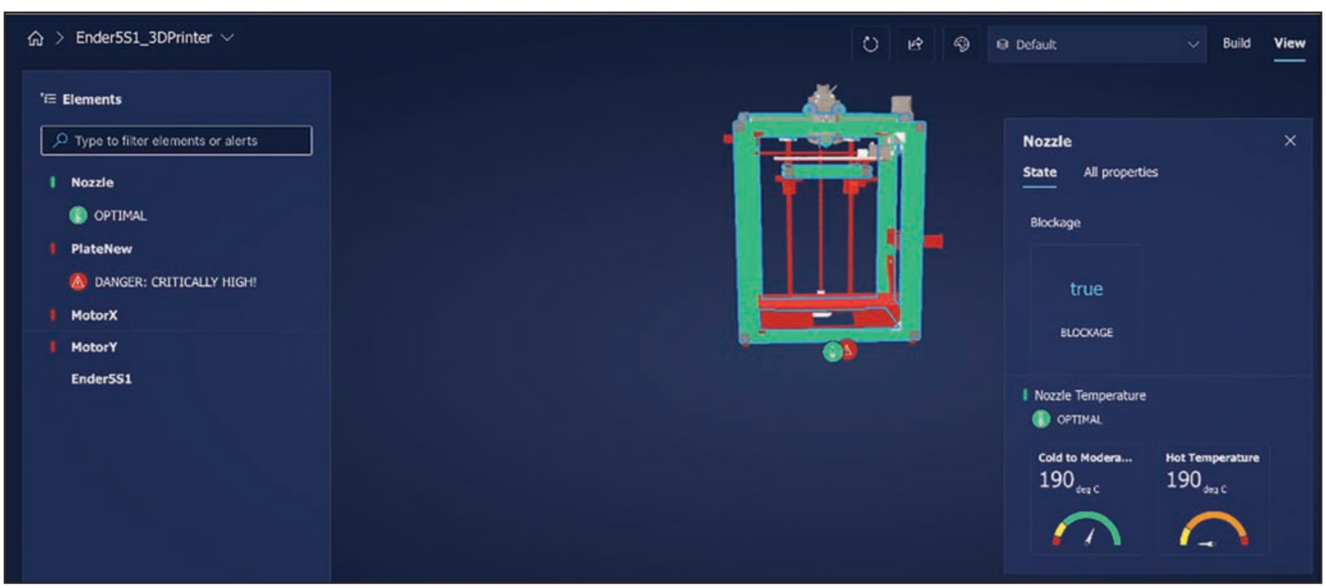

Figure 25. Example 3D printer digital twin created in the Azure software.

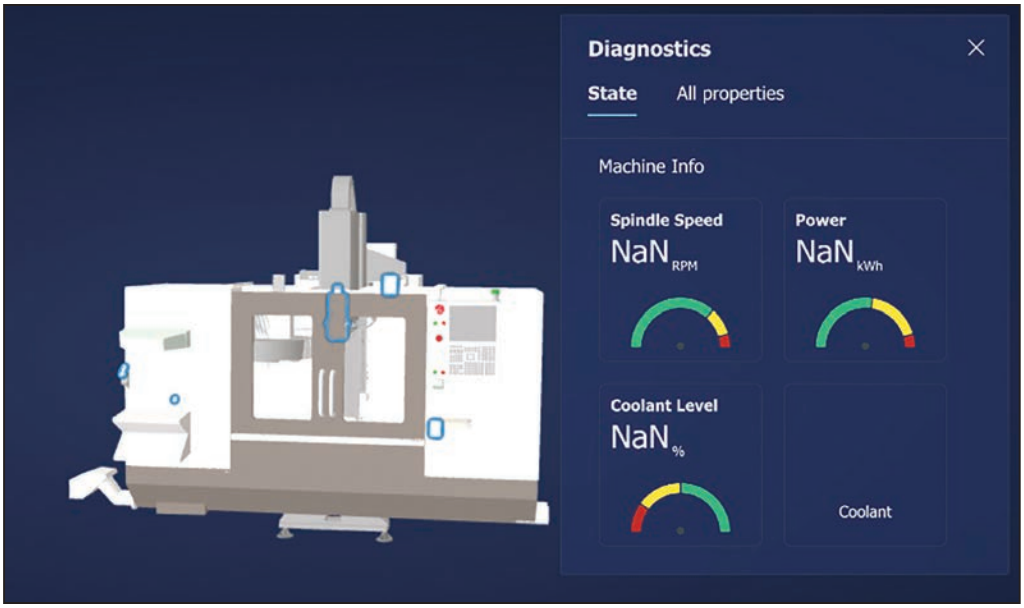

Figure 26. Example Haas mill digital twin created in the Azure software.

lenges facing the instructor were some difficulties encountered in obtaining Azure licensing and some students were not familiar with some of the programming languages used.

Adding a computer equipped with sensors for vibration, temperature, and energy usage that can interact with the controller of computer numerical control (CNC) equipment can provide an opportunity to collect useful data. Computers interconnected with existing CNC equipment have other advantages, such as directly downloading CNC programs generated using computer-aided manufacturing (CAM) software. The computer can connect to 3D scanning equipment for part verification and inspection. The computer can also be used to review videos for equipment safe operating procedures (SOPs) and tracking user safety training. Various sensors to monitor machining parameters for manufacturing research topics can include use time, milling spindle rpm, feed rates, lathe rpm, spindle forces, or tool forces (see Figures 27-29).

In this example, the goal is to adjust the spindle speed and feed rate to their optimal values. The optimization of the machining process improves the sustainability of the process. Minimizing chatter and vibration in the milling process can reduce energy consumption and extend tool life.

Other new topics added to the Four Pillars, such as *Generative Design*, can be easily incorporated into existing engineering graphics courses in CAD design. *AM* methods can be introduced to students in graphics and/ or product design courses. Projects that incorporate AM technologies can introduce students to the pros and cons of the seven ASTM AM categories from the viewpoint of product purpose: form, fit, and function.

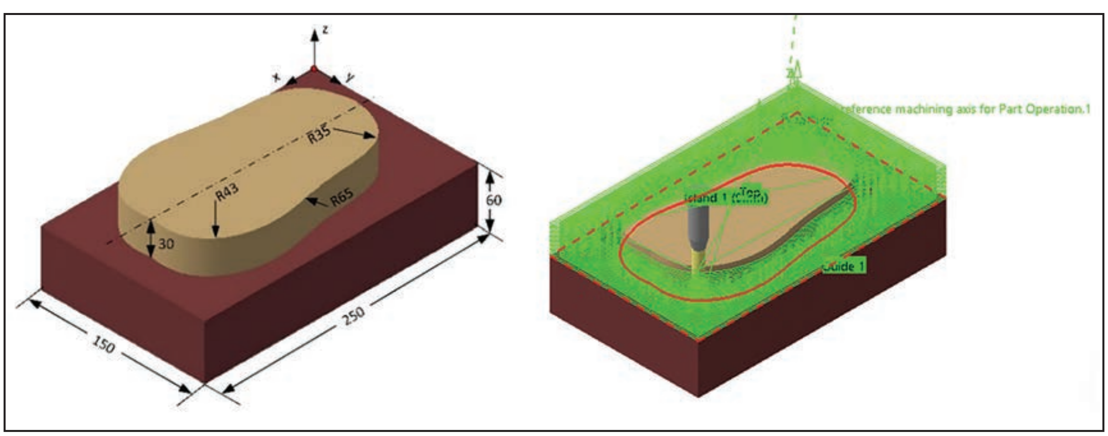

Figure 27. Sample part used for vibration and current monitoring,

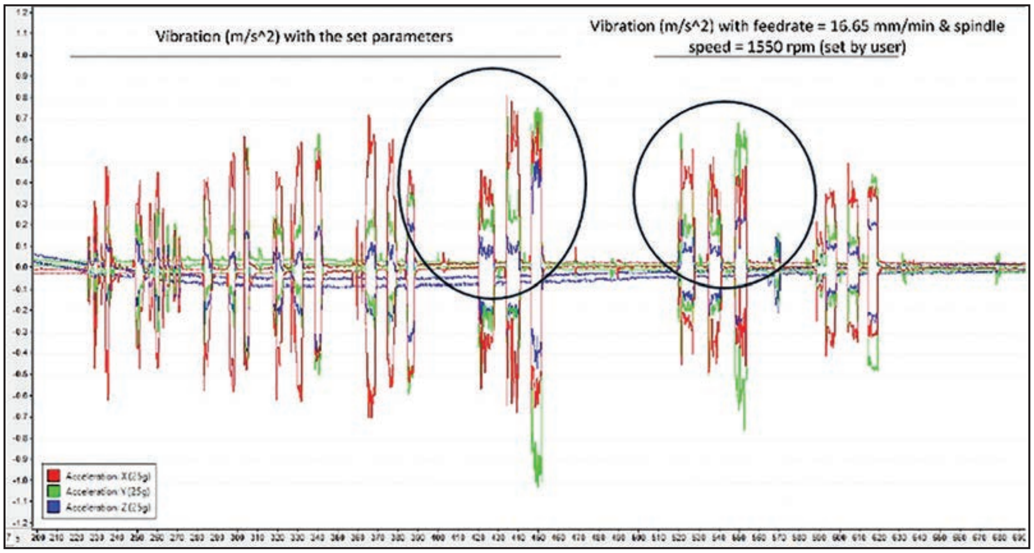

Figure 28. Example vibration during the machining of the sample part.

All added and revised topics in the Four Pillars are important to include in the education of manufacturing students. Some topics can be addressed in undergraduate courses, whereas others may be more appropriate for graduate education with a heavy emphasis on analysis. Some topics can encompass an entire semester of a course, and others can be presented in a single lesson. As an industry professional, it is important to understand the topics that manufacturing program graduates possess. As illustrated by authors (Labyak & Irwin 2023), the Four Pillars can be used for continuous improvement to analyze new or existing manufacturing curricula.

5. Implementation of Revisions

A variety of barriers may exist facing industry and academia alike in implementing some of the Four Pillar topics into the curriculum. There are things like the added equipment cost, training to update faculty or manufacturing personnel in new technology, and space required to set up new laboratories. Some potential strategies to overcome these are submitting proposals for state, federal, or private foundations in support of these initiatives. Manufacturing professionals and educators can benefit from industry and society conferences that offer training sessions in digital technologies, robotics, and automation. Also, there are opportunities for faculty to be trained in new technologies through outreach activities offered by NSF-sponsored projects.

6. Conclusions

The revision of *The Four Pillars of Manufacturing Knowledge* reflects the evolving landscape of advanced manufacturing, integrating Industry 4.0 concepts and aligning with updated accreditation standards and SME's Body of Knowledge for CMfgE and CMfgT certification programs. With significant

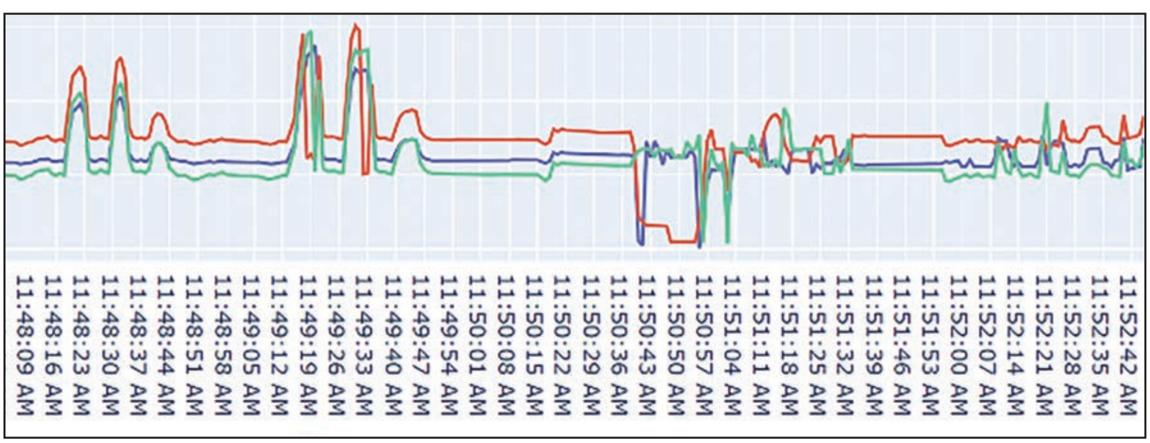

Figure 29. Example current (in ampere) during the machining of the sample part.

changes in eleven of the twelve knowledge blocks, this updated framework ensures that both academia and industry have a comprehensive model for modern manufacturing education. The most substantial revisions, particularly in the Industry 4.0 and Automated Systems and Control, as well as Process Design, highlight the growing importance of digital technologies, automation, and data-driven decision-making in manufacturing.

By examining these changes and providing practical applications for education and research, this paper serves as a valuable resource for educators, industry professionals, and policymakers. The insights gained from this study will help shape the future of manufacturing curricula, ensuring that graduates are equipped with the necessary skills to thrive in an increasingly digital and automated industry.

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John Irwin

Dr. John Irwin is a tenured Professor, Mechanical Engineering Technology/Chair of the MMET Department in the College of Engineering, at Michigan Technological University. He holds a Doctorate in Curriculum and Instruction from Wayne State University and conducts research on teaching and learning in computer-aided design, analysis, and manufacturing subjects.

Ismail Fidan

Ismail Fidan, Ph.D., is Editor-in-Chief of the Journal of Engineering Technology and also serves as its Communication Editor. He is a Professor of Engineering Technology at Tennessee Tech University, where he leads research and education initiatives in advanced manufacturing, additive technologies, and STEM outreach at both national and international levels.

Neil Littell

Dr. Neil Littell is Associate Professor, Director of Project Management Programs, and Kraft Family Scholar at Ohio University's Russ College. He specializes in digital transformation, digital engineering, strategic project management, and product lifecycle management, frequently consulting with Fortune 100 companies.

Suzy Marzano

Ms. Suzy Marzano is Sr. Manager of Industry Development and Technical Activities at SME. Marzano leads SME's Technical Community and Committee engagement platform to advance the Manufacturing ecosystem. Marzano provides oversight and management of industry programs and services, including advisory boards, community and committee programs, and research and insights.

David M. Labyak

David M. Labyak, PhD, is an Assistant Professor in the Manufacturing and Mechanical Engineering Technology Department at Michigan Tech, teaching Machine Design, Finite Element Analysis, and Mechatronics. He is in his eighth year of teaching at Michigan Tech. Prior to teaching, he spent 25 years in industry.

Scott Wagner

Dr. Scott Wagner is an Associate Professor in Manufacturing and Mechanical Engineering Technology at Michigan Tech. Holding a PhD in Mechanical Engineering, his research centers on metal forming techniques, including hydroforming, friction stir processing, and incremental forming. He also brings 11 years of industrial experience to his role.

Anis Fatima

Dr. Anis Fatima is an accomplished academician in the Department of Manufacturing and Mechanical Engineering Technology at Michigan Technological University, with over eighteen years of experience in academia. Dr. Anis Fatima has a proven track record as a researcher, with expertise in bridging the gap between traditional manufacturing practices and modern advancements such as digitalization, sustainable manufacturing, and circular economy principles.

Amna Mazen

Dr. Amna Mazen is an Assistant Professor at Michigan Technological University with expertise in robotics, digital twins, ROS, deep learning, and computer vision. She holds a Ph.D. in Electrical Engineering and Computer Science and has over twelve years of teaching experience in mobile and manipulator robot systems.

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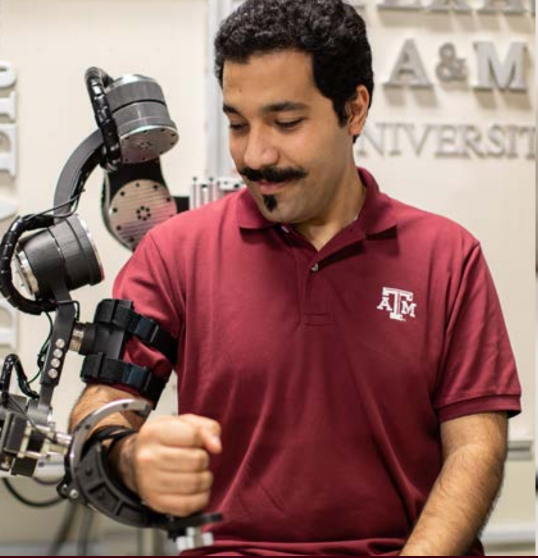

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